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Water Use by the Oil and Gas Industry: An Assessment of Two Texas Regions

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Water Use by the Oil and Gas Industry: An Assessment of Two Texas Regions

by

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Thesis

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Dedication

I would like to dedicate this thesis to my family, who has consistently supported me through my academic endeavors. I couldn’t have gotten this far without them. And I would also like to dedicate this work to my friends who have supported me, kept me sane, and encouraged me during my research.

Acknowledgements

I would like to say a special thanks to Dr. J.P. Nicot and Dr. William Fisher who supported this research and my passion for the topic. Without their direction and support this research would not have been possible. I would like to also acknowledge my mentors from the American Water Works Association (AWWA), Adam Carpenter and Alan Roberson, for their advice throughout this research. The support system that Adam and Alan gave me to do this project is something that I am extremely grateful for. I could not have accomplished this project without them. I would also like to thank the several people from the University of Texas at Austin, who provided me insight when I needed it most. And I would like to thank Sean Lieske, who assisted me in several aspects of my research as well. Finally, the various stakeholders who contributed to my research truly holds a lot of value for me and this thesis, I would like to acknowledge their efforts, time, and passion about getting the information to me. I appreciate their efforts to discuss this topic with me.

Water Use by the Oil and Gas Industry: An Assessment of Two Texas Regions

by

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The University of Texas at Austin, 2013

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The oil and gas industry makes up approximately 1% of Texas's overall water use (TWDB, 2012), but assessing water use on a regional and county level could show that the impacts from the oil and gas industry can be greater on a local level. Water planners within in Texas are becoming more concerned with how regional and local impacts from upstream development of oil and gas. These areas are under water-stressed conditions due to drought. To better understand potential local use impacts this study conducted qualitative and quantitative analyses. The qualitative analysis gathered input from stakeholders including representatives in the oil and gas industry, regulatory sector, and Texas water planning entities. This study utilized two public databases called FracFocus to assess average water use trends over time for the Eagle Ford region in south Texas and the Spraberry/Wolfcamp formations in west Texas.

According to the qualitative analysis conducted trends toward increasing use of brackish groundwater and some recycling and reuse techniques by some operators are occurring in both regions. Also, there were slightly increasing trends of average water use per a well over time for both regions between January 2011 and April 2013. This analysis can be misrepresentative of the cause of the change in water use by the oil and gas industry, and therefore requires more data. The FracFocus database lacks the direction of the well, the lateral length of the well, and the mass of the proppant. These inputs would allow for a holistic analysis by water planners.

The oil and gas industry can have local impacts on water use in particular regions. An increasing importance for regional water planners to have access to accurate oil and gas water use data is apparent. Collaboration between the oil and gas industry and Texas regional water planners will be a key component in areas with heavier mining water demands. Conclusively, the need for a more robust data set for regulators, industry professionals, and other stakeholders to access will benefit the strategic assessments oil and gas water use on local levels.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Study Objectives

This study examines water quantity issues surrounding play development in the Eagle Ford area located in south Texas and in the Spraberry/Wolfcamp formation area in west Texas. Upstream development of oil and gas formations is complex and several stakeholders are involved in the process, including the oil and gas operators, regulators, landowners, and regulators. Often, Texas water planners and regulators are not included in this multifaceted development process. Controversy surrounds this issue and can cause heated debate, misinformed statements, and a decrease in collaboration between different entities that have an interest in water use and hydraulic fracturing. This study aims to clearly define the issue of water usage by the oil and gas industry within Texas and compare the current state of the south and west Texas regions. This study's objectives are to:

- Examine water use by the oil and gas industry in the south and west regions of Texas,
- Assess impacts on local water use in these two regions with publically available data,
- And evaluate the collaboration between state regulatory agencies, water planning entities, and the oil and gas industry in the regions.

1.2 Structure of Thesis

The first chapter of this thesis is a brief overview of the recent developments in the oil and gas industry, specifically in the two regions being assessed in this analysis as well as the regulatory framework the oil and gas industry operates under. The second chapter revolves around the water planning structure of Texas and the recent status of water use in Texas. Chapter three of this thesis reviews other major studies that focus on water use by the oil and gas industry in these two Texas regions. The fourth chapter discusses the methods for the analyses of this study. The chapter five examines the results and discusses some of the implications these results may have for the two regions. And chapter six concludes the thesis with a finalized assessment.

1.3 Overview of Oil and Gas Development

The extraction of oil and gas from formations that have low permeability requires advanced technology, which commonly includes the process of hydraulic fracturing, horizontal drilling, and geo-steering – an advanced process to guide the drilling path with accuracy (ALL & GWPC, 2009; Spellman, 2013). Hydraulic fracturing (HF), also known as "fracking" or "fraccing," usually happens thousands of feet beneath the surface of the ground where an injection of a mixture of fluids and sand at high pressure is used to create fractures, or cracks, near the drilled well (USGAO, 2012; Spellman, 2013). The HF fluid consists of 99% water and sand, and 1% of other ingredients to ease the fracture producing process (ALL & GWPC, 2009; RCC, 2013a; USGAO, 2012). Over the past decade technology that enhances oil and gas extraction, including HF technology advances and horizontal drilling, has set in motion rapid growth in the extraction of oil and gas from formations with low permeability in the U.S., especially in Texas (USGAO, 2012). Upstream oil and gas development, especially shale formations, have many different environmental impacts comprising of air, water, and community development issues. These concerns are diverse across the various regions where the oil and gas resources are extracted (ALL & GWPC, 2009).

HF has been around since the early 1950's and large scale HF events began to occur in the 1980's (Savage, 2012). HF transpires several thousand feet below the fresh groundwater aquifers that are utilized by other water users (Fisher and Warpinski, 2012; King, 2012). On average in Texas, HF occurs at depths of over 5,000 feet, while the aquifers that are utilized for drinking resources are less than 1,000 feet (Fisher and Warpinski, 2012; Savage, 2012). HF is the most water intensive part of the life cycle of the oil and/or gas well during primary recovery. Water for the primary extraction process, which in this analysis is HF, is only one stage of an oil or gas well's water life cycle. There are three major stages of an oil and gas well's life during upstream development including the drilling of the well, the opening of pathways for resource extraction, and the production from the well. The oil and gas industry mainly utilizes the HF process to extract resources, especially for formations with low permeability which include shale plays. The drilling stage for a well uses a relatively small amount of water compared to the HF process, and therefore is not significant to include in this particular water use study (King, 2012).

Oil and gas wells have a transient and temporary nature, especially when looking at long term planning above a thirty year threshold. Market conditions for the oil and gas resources are constantly changing and are affected by many different factors including regulations, geopolitical implications, and international market factors. It can be difficult to predict new technological advances, market shifts, and other influences that can affect the rate and location of upstream development for oil and gas resources over a long term period. Many water planners in Texas are consistently planning for fifty years or further into the future, and therefore the timelines of these two sectors do not align.

1.4 Overview of Texas Oil and Gas

Currently, 238 of the 254 counties in Texas have oil and gas extraction practices occurring within them (Savage, 2012). There are over 150,000 active oil wells and over 104,000 gas wells in Texas, making Texas a leading energy producer across the United States (EIA, 2013a; Savage, 2012). Texas has several major oil and gas formations that have been extensively developed within its boundaries, including the Eagle Ford shale play in south Texas and formations within the Permian Basin in west Texas. Both the Eagle Ford and the Permian Basin regions can be seen in *Figure 1.1*, showing the major shale plays within the U.S. *Figure 1.2* shows the Eagle Ford region in south Texas and the Permian Basin in west Texas that includes the Spraberry/Wolfcamp formations. Although, the Eagle Ford area is relatively new compared to the west Texas region that has been under development since the 1950's, both areas have undergone significant growth in the past decade (Pioneer, 2012; RRC, 2013b).

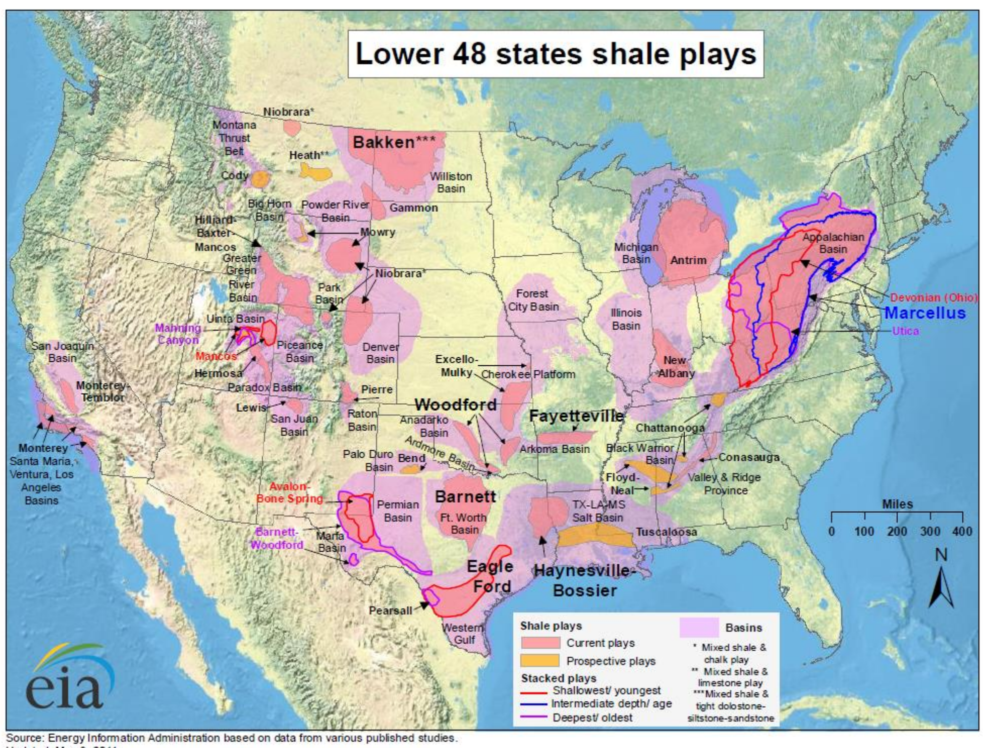


Figure 1.1 – This is a map of shale plays within the lower 48 states of the U.S., including the Eagle Ford region and the Permian Basin region. The locations of these two Texas regions are shown on a national level (EIA, 2011a).

Also, these two regions have also been selected for analysis due to the similarity in stress on water use that the regions face. These two areas in south Texas and west Texas also are the leading oil and gas fields by rig count and will have a significant amount of activity in the near future (Pioneer, 2013a). The similarity in potential growth, current development, water stresses, and regulatory oversight allows for a comparison between the regions. Although there are some similar factors the two regions share, there are also large differences that must be accounted, including the geological differences and the timeline of development between west and south Texas.

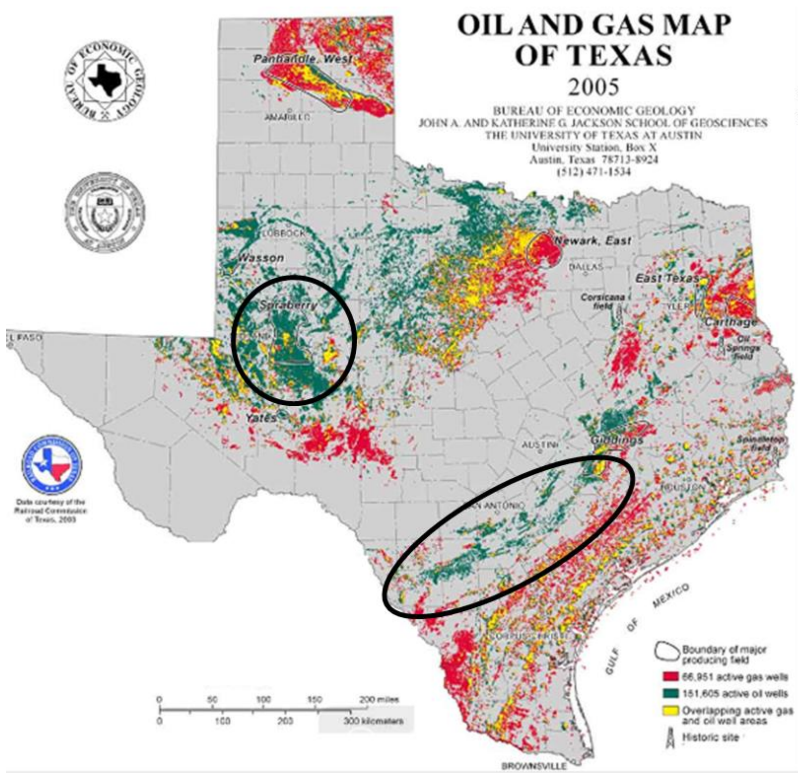


Figure 1.2 – This map shows the active oil and gas wells in each region. This 2005 map misses much of the recent growth in the two regions, especially in south Texas, but shows that locations of each region being analyzed relative to other oil and gas development in Texas (BEG, 2005, modified).

1.5 Overview of Regulations for Onshore Oil and Gas

Texas has several different levels of regulatory framework that the oil and gas industry operate under, although most of the regulations are implemented by the state (ALL & GWPC, 2009; Rahm, 2011). The first tier of governing framework comes from the federal level. The regulatory oversight that federal entities have implemented from the Clean Water Act (CWA), the Safe Drinking Water Act (SWDA), the Clean Air Act (CAA), and the National Environmental Policy Act (NEPA) is minimal. Most federal laws exempt the oil and gas industry, but many states, like Texas, implement regulations to make up for the exemptions (Rahm, 2011). Federal laws mandate that the state implements the CWA's surface discharge regulations and the SWDA's underground injection policies and does not exempt the oil and gas industry (Rahm, 2011; Spellman, 2013). The CWA's surface water discharge is less applicable in the two Texas regions being assessed in this study, since a small amount of surface water is located within these areas. The SWDA provision requires a permitting process for the underground injection of waste fluids (not the fracturing itself), or the injection of diesel in the ground (Spellman, 2013). This is implemented by a state level program that has been approved by the U.S. Environmental Protection Agency (USEPA) (Spellman, 2013). The USEPA is currently undergoing a multi-year study on the impacts of HF and many federal policy makers are awaiting the results of this study. One major aspect of the USEPA study (2012) is the water acquisition section, which is analyzing whether large water withdrawals by the oil and gas industry have negative impacts on drinking water resources, both for groundwater and surface waters. The USEPA study, when complete, will help inform federal policymakers on the different issues surrounding HF and drinking water resources.

On the state level, there are two important agencies that regulate the oil and gas industry within Texas, the Texas Railroad Commission (RRC) and Texas Commission on Environmental Quality (TCEQ). The RRC is the primary regulating entity for the oil and gas industry in Texas and is also tasked to work with other agencies to promote efficient regulatory processes for the industry while not hindering economic development (Porter, 2013; TX House, 2013). The RRC is a unique state entity in that has an international presence, and many oil and gas industry stakeholders assess what the RRC is doing in terms of regulations for the industry (TIPRO, 2013). To fulfill the SWDA requirements, TCEQ provides permits for underground injection control (UIC) to compliant companies that are injecting diesel into the ground during HF events or waste disposal injection wells. (TCEQ, 2013) Most recently the RCC amended several policies to promote recycling as well as to help make the oil and gas industry be more environmentally conscious (Porter, 2013). The RRC jurisdiction for upstream oil and gas development includes (Rahm, 2011; Savage, 2012):

- Requirements for well spacing, density, drilling, completions, production, and well plugging for each field in Texas,
- Standards for pipelines,
- Minimal measures to follow for safe practices,
- And, waste management policies for the storage, transport, and disposal of oil and gas upstream wastes.

The RRC does not have jurisdiction over traffic, noise, scenic impacts, property values, or zoning (Savage, 2012). When it comes to water use the RRC encourages and regulates recycling, while the TCEQ holds temporary surface water rights and manages certain water withdrawals, mainly associated with surface water (Savage, 2012).

1.6 State of the Eagle Ford Shale Play

The Eagle Ford shale play sits in a large area comprised of approximately twenty-seven counties in south Texas (RRC, 2013b). The play overlays two major groundwater supplies, the Edwards aquifer and the Carrizo-Wilcox aquifer (TWDB, 2012). In 2012, the Eagle Ford had 4,145 drilling permits issued compared to the 26 permits issued in 2008, showing an exponential rise over four years (Porter, 2013). The Eagle Ford has consistently shown increased growth over the past two years, and the region is recently reported to be yielding 672,952 barrels per day, which is a 54% increase in production between April 2012 and April 2013 (Murtaugh, 2013). *Figure 1.3* shows development in the Eagle Ford shale rapidly expanded in 2011 and continues to be an active area of increased development for the oil and gas industry (Porter, 2013; RRC, 2013b). This fast expanding shale play covers over 20,000 square miles and has valuable crude oil and condensate resources making the it ideal for continued development (Bazan, et al., 2012; Porter, 2013). Also, there has been a decrease in cost associated with drilling a well since 2009, which gives way to easier development of the area (Kaiser, 2011). There are expectations that there will be over 85,000 more wells drilled in the Eagle Ford field, and predictions that the peak of production will likely occur within the next decade as the area reaches double the current production (Hiller, 2013).

The geological attributes along with the remote south Texas location of the Eagle Ford play make it unique for this study, especially with increasing water needs in the region due to a drought. The shale play has relatively more carbonate making it more brittle and therefore easier to introduce hydraulic fractures in the formation (RRC, 2013b; Porter, 2013). *Figure 1.4* shows where the oil and gas production in the Eagle Ford occur. Northern portions of the region are mainly comprised of oil producing wells, while the southern portion of the play is composed of dry gas production (RRC, 2013b).

Growth in Eagle Ford Area

OIL PRODUCTION
Eagle Ford Shale - Annual Growth

	B/D	Growth
2008	358	
2009	844	136%
2010	11,986	1,320%
2011	126,459	955%
2012	338,911	168%

GAS PRODUCTION
Eagle Ford Shale - Annual Growth

	MMCF/D	Growth
2008	8	
2009	47	487%
2010	216	360%
2011	959	344%
2012	964	0.5%

CONDENSATE PRODUCTION
Eagle Ford Shale - Annual Growth

	B/D	Growth
2009	1,423	
2010	13,708	863%
2011	70,934	417%
2012	72,126	1.6%

DRILLING PERMITS
Eagle Ford Shale - Annual Growth

	Permits	Growth
2008	26	
2009	94	261%
2010	1,010	974%
2011	2,826	180%
2012	4,145	46%

PRODUCING OIL WELLS
Eagle Ford Shale - Annual Growth

	Wells	Growth
2009	40	
2010	72	80%
2011	368	411%
2012	1,262	243%

PRODUCING GAS WELLS
Eagle Ford Shale - Annual Growth

	Wells	Growth
2008	67	
2009	158	136%
2010	550	248%
2011	855	55%

Figure 1.3 – This figure shows the growth that the Eagle Ford area has experienced since 2008. There have been exponential increases in numbers of drilling permits issued, producing oil and gas wells, and the production of oil, gas, and condensate (Porter, 2013).

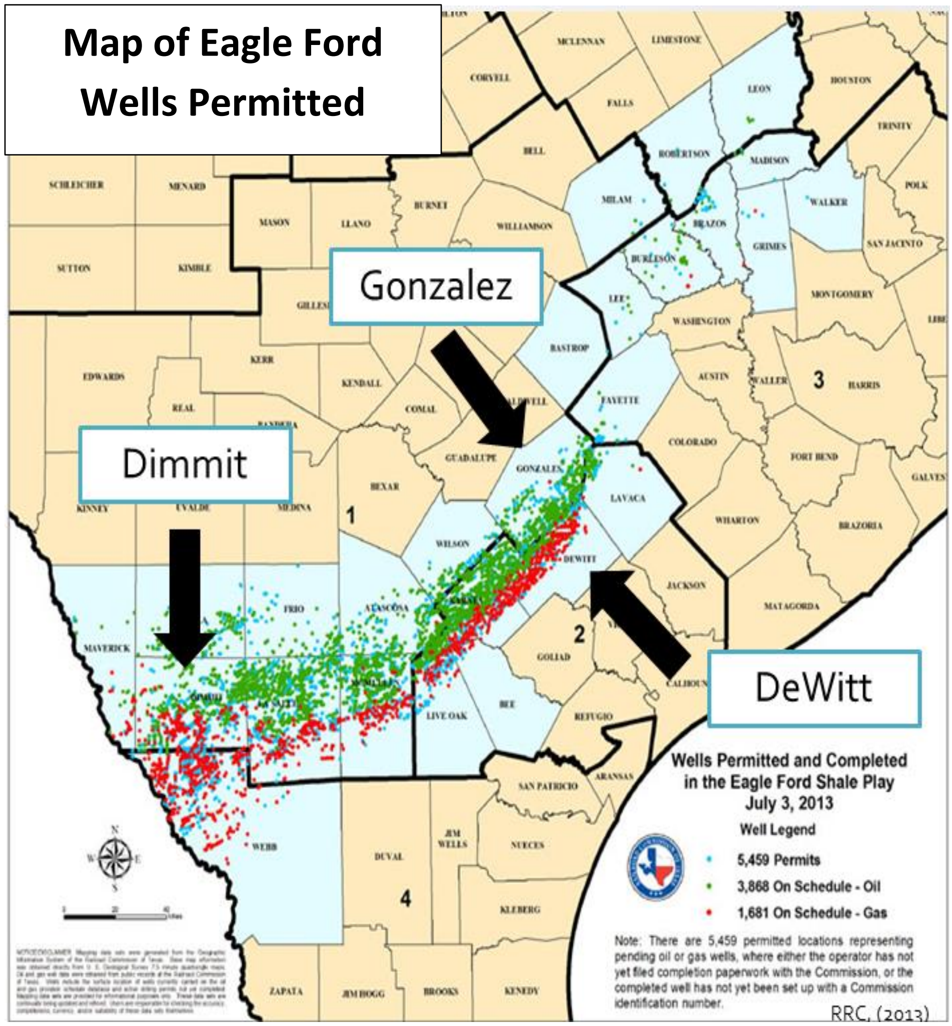


Figure 1.4 – This figure shows the location of the Eagle Ford play in south Texas, as well as the different wells permitted within the region by the RRC. Dimmit and Gonzales counties consist mainly of oil well permits, while DeWitt county has a significantly amount of gas well permits (RRC, 2013b, modified).

Approximately 90% of the water utilized by oil and gas companies in the Eagle Ford is groundwater (Nicot, et al., 2012). The wells being analyzed in the Eagle Ford are all horizontally fractured wells, not vertical wells. Horizontal wells tend to utilize more water due to their length being relatively longer than the vertical wells (Bai, et al., 2013; RRC, 2013a). Most of the wells in the Eagle Ford are horizontal wells according to EIA (2011b). Currently the Eagle Ford region has little recycling of produced water because of costs associated with recycling/reuse of produced water, ease of current disposal practices, and regulations (Nicot, et al., 2012). Most companies within the Eagle Ford shale play inject waste products post HF events into an underground injection well because the underground injection of these fluids is relatively easier compared to other options that have increased transportation costs and associated legal implications (RRC, 2013b). Although there are several different effective recycling/reuse technologies available, the Eagle Ford region does not utilize these technologies on a wide scale due to cost comparisons, risk assessments, and relative locations of the well sites (TX House, 2013). The lack of motivation to recycle/reuse in the Eagle Ford shale play is caused by three major factors (TX House, 2013):

- The cost of waste disposal versus cost of acquiring the recycling technologies
- The lack of reliability of reused water,
    - After one year only about 20% of the flowback water in the Eagle Ford has re-surfaced
    - The location and amount of water available relative to the needs of the well the recycled/reused water will be used at may be inconvenient
- The risks and liabilities associated with the storing, transport, and liability of the produced water during treatment and distribution to other HF jobs

Although recycling/reusing water in the Eagle Ford shale play is minimal compared to other shale plays, the use of brackish water has gained momentum within the region (Porter, 2013; Strause, 2013). Brackish water in this study is groundwater with a concentration of total dissolved solids (TDS) between 1,000 milligrams per liter of water and 10,000 milligrams per liter of water (LBG, 2003; TWDB, 2013a). Even though brackish water usage in the oil and gas industry reduces freshwater use, several negative aspects have potentially prevented it from becoming a more prevalent. The fact that brackish water in the Eagle Ford shale region is often located at depths of 4,000 feet or greater increases the cost of drilling for the water immensely (LBG, 2003; NGWA, 2010). Also, the pump rate of brackish water is significantly slower than the rate for freshwater, making the reliability of brackish water sources less than freshwater sources and usually necessitates the operator to drill more than one well to acquire the needed water for the HF job (LBG, 2003; Nicot, 2013). The dynamic brackish water systems are not as well understood as the freshwater systems, and there could be other unforeseen consequences of utilizing brackish water.

1.7 State of Spraberry/Wolfcamp Formations

The Permian Basin is located in west Texas and parts of New Mexico, and has three major sub-sections in it, including the Midland Basin, Central Basin Platform, and the Delaware Basin. The Permian Basin encompasses fifty-nine counties and has over eleven different producing formations within it (King, 2012; RRC, 2013c). The depths of the oil and gas wells located in this area reach between a few hundred feet to five miles beneath the surface, showing the vastly diverse upstream development the region experiences (RRC, 2013c). *Figure 1.5* shows the producing oil and gas wells in the Permian Basin region, where green colored dots represent oil producing wells and red colored dots represent gas producing wells. *Figure 1.6* shows the top producing fields within the Permian Basin, with the Spraberry field climbing to the number one position in the region since 2009.

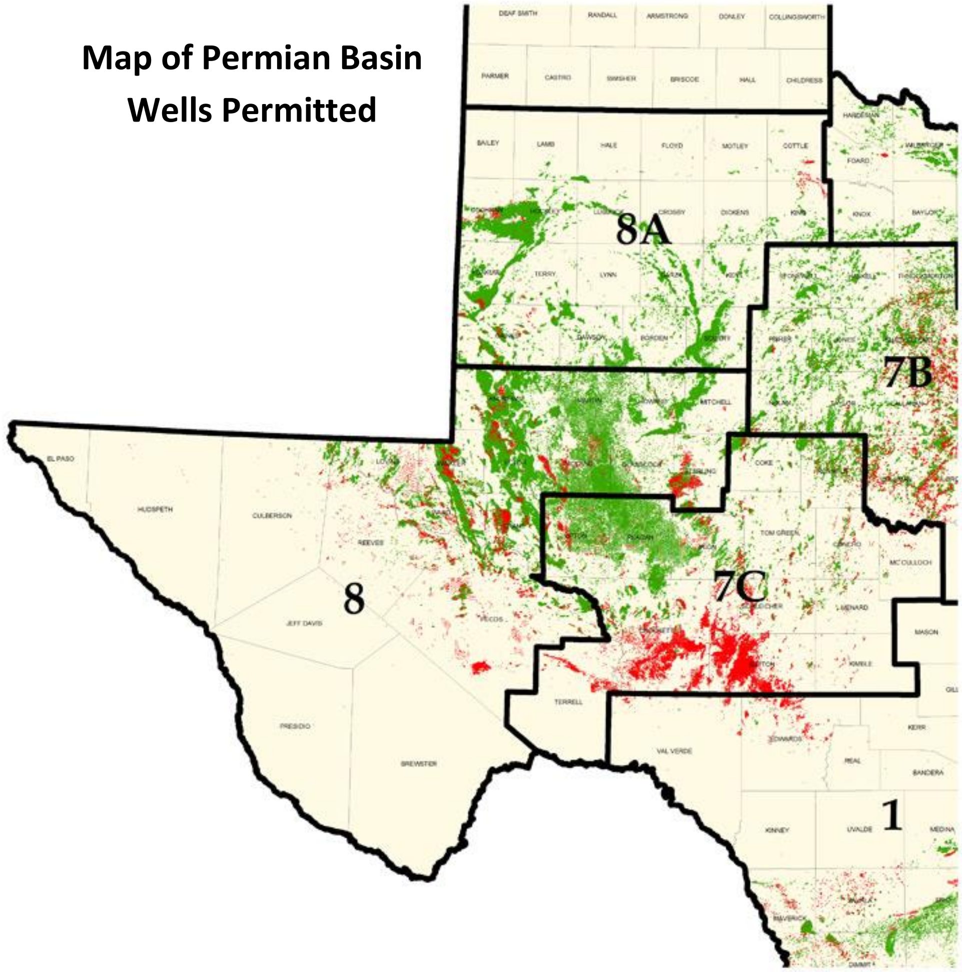


Figure 1.5 – This figure shows the different wells permitted in Permian Basin area. Green dots on the map represent oil wells permitted by the RRC and red dots on the map represent gas wells permitted by the RRC. A majority of the Spraberry/Wolfcamp area has oil permitted wells on this map (RRC, 2013c).

The Spraberry/Wolfcamp formations located in west Texas have a growing role for the oil and gas industry within Texas. These two formations are located in a region with consistent production over the past 80 years (Dutton, et al., 2005). This analysis specifically assesses the Spraberry and Wolfcamp formations within the Midland Basin. These two formations have approximately 50 billion recoverable barrels of oil, making it the second largest oil field in the world (Pioneer, 2013a). To put that in perspective, the EIA (2013b) has estimated that the Eagle

Ford has about 6.3 billion recoverable barrels of oil. The Spraberry formation lies on top of the Wolfcamp formation and the area where these two formations comingle within the Midland Basin are commonly referred to as the Wolfberry trend (Dutton, et al., 2005). The Spraberry formation is between 7,000 and 8,000 feet beneath the surface, while the Wolfcamp formation is between 8,000 and 10,000 feet (Dutton, et al., 2005). This study assesses three different sections within the Spraberry/Wolfcamp formations: an area where just the Spraberry formation is located, the Wolfberry trend, and an area where just the Wolfcamp shale formation occurs. The distinction between these three different areas is important in assessing the geological attributes and current production of oil and gas within the area being analyzed.

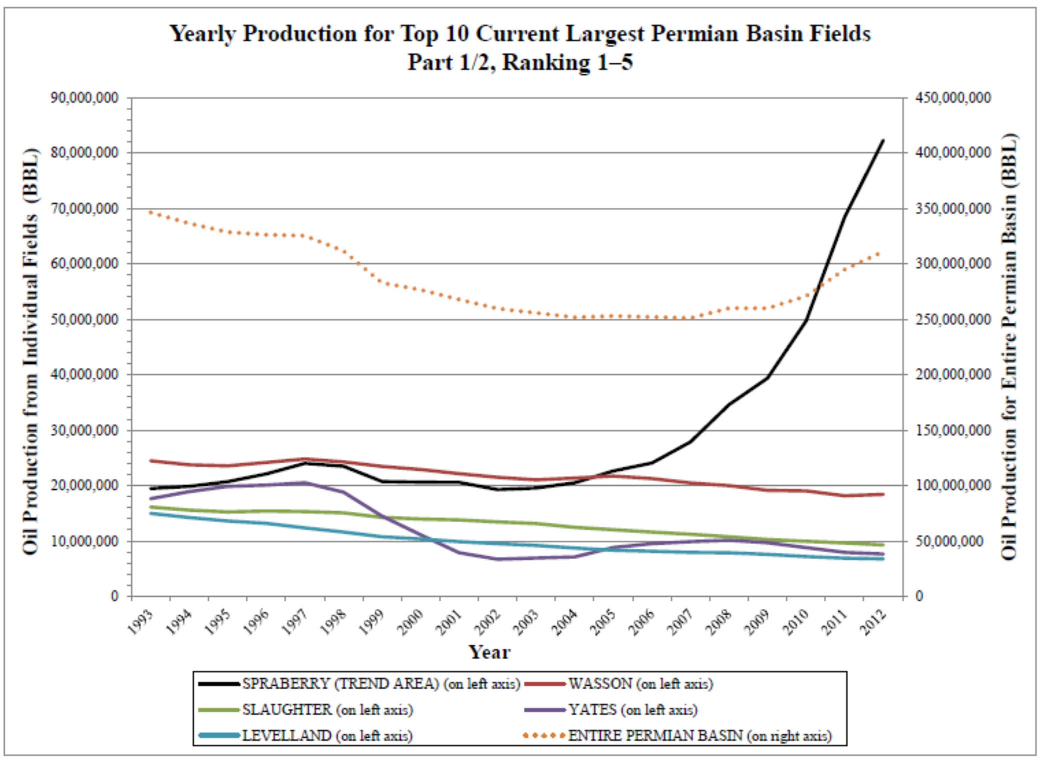


Figure 1.6 – This graph displays the five top producing fields in the Permian Basin, including the Spraberry/Wolfcamp area, displayed by the solid black line in the graph. It can be seen that there is drastic growth since 2009 in this area (RRC, 2013C).

The concept of “stacked plays” makes this area highly viable for increased development and production of oil and gas (OGJ, 2013). The area where the two formations comingle, the Wolfberry trend, will prove to be a highly profitable area. An operator can target multiple levels resources in a single drilling well, increasing the “pay zone,” or zone where the oil and gas can flow from the formation into the well for extraction (OGJ, 2013). Vertical wells are used to drill within the thick pay zone of the Spraberry, as is the case with parts of the Wolfberry Trend (Pioneer, 2013a; Dutton, et al., 2005). The Wolfcamp has mainly horizontally drilled wells, and can have long horizontal extensions, or laterals, of the wellbore of several thousand feet (Pioneer, 2013a). The “stacking” of plays will continue to have large impacts in cost benefits analyses for companies looking to develop this area.

The Spraberry and Wolfcamp formations in this study span roughly ten counties and are approximately 5,000 square miles (Pioneer, 2013a). The Spraberry formation is a very fine-grained sandstone formation with natural fractures that cause high rates of production during the beginnings of the production phase of a well’s life and the Wolfcamp formation is a carbonate, shale play (Dutton, et al., 2005). The Spraberry/Wolfcamp formations have a cumulative production of over one billion barrels produced and hold over 14,000 producing wells within the area (Pioneer, 2013a). The Spraberry/Wolfcamp is the second largest oil field in the world and the largest oil field in the U.S. (Pioneer, 2013b). Between 2009 and 2012 production growth was attributed to vertical activity, while post 2012 production growth has been and is expected to continue to be attributed increasingly more towards horizontal activity (Pioneer, 2013b). Within the Spraberry/Wolfcamp region, Pioneer Natural Resources is currently the largest driller and producer and holds about 50% of the leases in the region (OGJ, 2013; Pioneer, 2013a). These plays lie in close proximity to each other and therefore are analyzed as one unit within this study, see *Figure 1.7*. The Spraberry formation covers approximately ten counties, while a majority of the southern portion in *Figure 1.7* shows the location of the Wolfcamp formation which includes Upton, Reagan, and Irion counties (Pioneer, 2013a). Also, there are multiple pay zone intervals within the Wolfcamp shale that are being targeted by operators for resource extraction (Pioneer, 2013a).

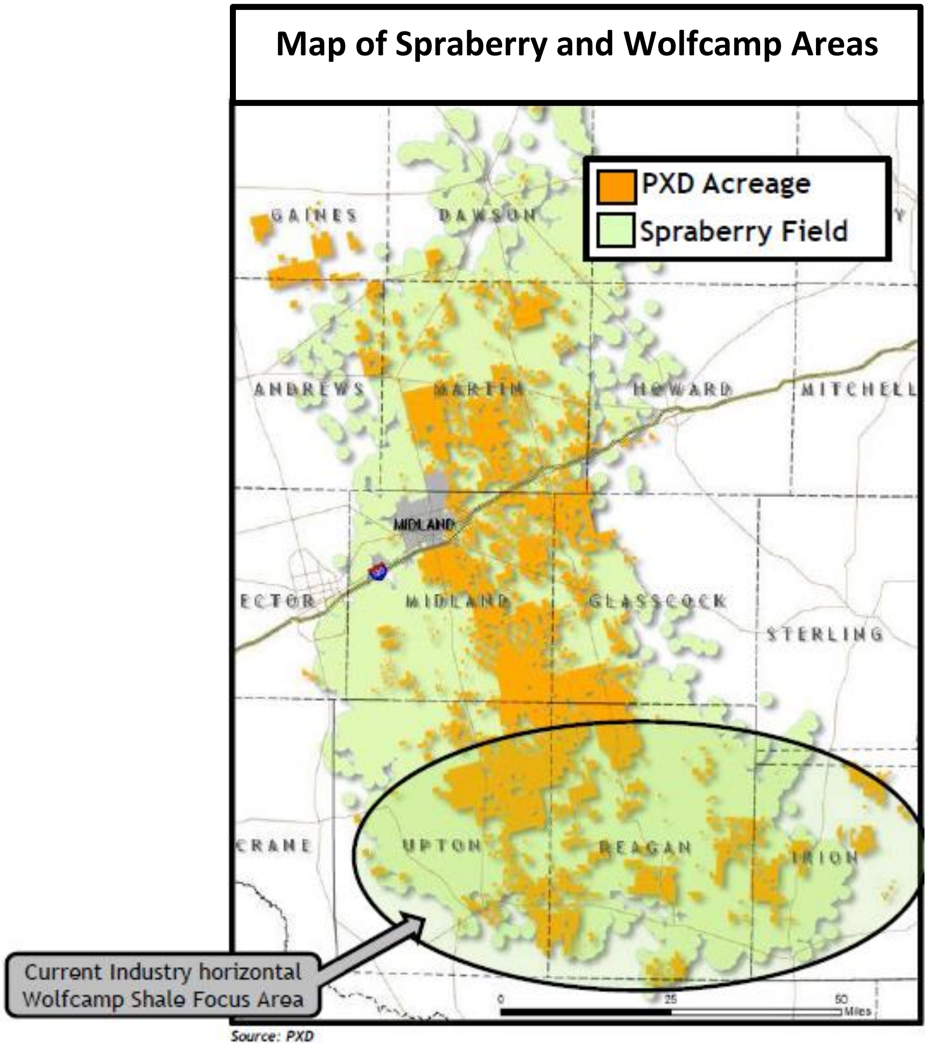


Figure 1.7 – This map shows the Spraberry and Wolfcamp fields in west Texas. The orange areas displayed on this map are the locations where Pioneer, the largest operator in this region, has leased (Pioneer, 2013a).

The Spraberry formation has significant amounts of vertical drilling relative to the Wolfcamp play (Dutton, et al., 2005). The Wolfcamp shale play has more horizontal drilling occurring within its boundaries (Dutton, et al., 2005). Within the Spraberry a movement towards deeper vertical drilling is being sought after to drive towards an improvement in production performance for the area (Pioneer, 2013b). And specifically in the Wolfcamp shale, where horizontal drilling is more active, the length of the horizontal laterals are being increased as the development of the field progresses (Pioneer, 2013b). With lateral lengths of over 5,000 feet in this formation, the Wolfcamp will continue to hold a promising production future for operators (Pioneer, 2013b). Since 2010, Pioneer Natural Resources, the largest operator within the Spraberry/Wolfcamp area, has increased the resource potential by over 400% (Pioneer, 2013b).

Pioneer holds approximately 900,000 acres in the Spraberry/Wolfcamp area and is the top producer in the region of the Midland Basin (Pioneer, 2013a). In the southern Wolfcamp section a large amount of oil is expected to be produced and horizontal drilling will be largely dominant here with significant resource potential of over 5,600 potential new drilling locations (Pioneer, 2013a). The expectation of an increase in over 1,000 feet for the average later length drilled in the southern Wolfcamp area in the next year by Pioneer will show an increase in profitability for the operator in the region, as well as an decrease in well spacing throughout the region, especially in Upton and Regan counties (Pioneer, 2013a). And production from vertical drilling is expected to decline by 10%, although an improvement in efficiency will come from successful transitions between vertical to horizontal drilling (Pioneer, 2013a). These changes in both fields in the area will have impacts on water resources needs.

Almost all of the water utilized to extract oil and gas resources in the Permian Basin area is sourced from groundwater (Nicot, et al., 2012). A majority of the water used is fresh water, while a small amount of water is brackish and recycled. The brackish water utilized is variable by operator, like in the Eagle Ford, but on average accounts for approximately 30% of the water used in this region (Nicot, et al., 2012). Recycling and reuse of flowback water accounts for about 2% of the water use in the Spraberry/Wolfcamp region (Nicot, et al., 2012). The amount of recycling/reuse of water also varies depending on the operator. For example, in a rare instance, the operator, Apache Corporation, in this region is recycling 100% of the flowback water that its wells produce, according to a recent *Reuters* news article, as well as mixing brackish water with that flowback for reuse in the area (Apache, 2013; Driver and Wade, 2013). After one year, about 75% of the flowback in the Spraberry/Wolfcamp region has occurred (Nicot, et al., 2012).

1.8 Assumptions

Several assumptions were made during this study to assist in clarification of the study approach and methodology, which are listed below.

- Water volume data reported is representative of the entire life cycle of the well, including drilling, HF, and other production needs, although the water volume data utilized account for just the HF state of a well's life cycle (King, 2012).
- A well can also have secondary and tertiary enhanced recovery during its life to gain more production of oil and gas from the well, but this assessment only analyzes water use for primary recovery extraction practices in both regions.
- All flowback water and produced water mean any fluids that are produced post the drilling or HF of an oil or gas well. Produced water is the fluids captured after the drilling process and flowback water is the fluids that flowback post a HF event (ALL, 2009; King, 2012). For the

purpose of this study both produced and flowback water will be effectively mentioned under one term, flowback water.

- Any water quantity data reported shows the water that is consumed, since water cannot be replaced back into the part of the water cycle it originated from.
- Any water defined as freshwater is water that is able to be utilized for human consumption in some point in time.

These are the major assumptions of this analysis. Oil and gas development across the U.S. varies immensely between regions and it is therefore important to understand these underlying assumptions for this study to transfer methods and regulatory analysis to different oil and gas upstream development locations.

Chapter 2: Overview of Water Use and Water Planning in Texas

2.1 State of Water Use in Texas

This study assesses different stakeholder perspectives in the development of oil and gas plays, and a major stakeholder that is a required part of this collaboration are the water planners of Texas that consistently assess how much water Texas will need in the future and whether the water supplies will be available for the demand. Water planning in Texas became robust after the drought of the 1950's, which is the drought of record for the state. Texas policymakers initiated a robust planning environment for water planning with state level entities, regional entities, and local entities. Currently in Texas there are over 25 million people that require more water than is available (TWDB, 2012). The population of Texas is expected to increase by over 80% between 2010 and 2060, and the needs for the various water users are only exacerbated by the current drought which had some of the worst conditions during 2011 (TWDB, 2012). There are several different water users by sector within Texas including: municipal, manufacturing, irrigation, livestock, steam-electric power, mining, and industrial (TWDB, 2012). The oil and gas industry's water use is included in the "mining" user category within the state water plan. The mining category represents the exploration, development, and extraction of several different natural resources, including oil and gas. This mining category represents approximately 1% of the state's total water use, and is expected to decrease between 2010 and 2060 (TWDB, 2012). Irrigation users account for over 50% of the state's water use and municipal usage is also a significant portion of water use in Texas (TWDB, 2012).

Texas has been experiencing a major drought through 2011 (TCEQ, 2012) which, as stated previously, was a period of large growth for the oil and gas industry in the Eagle Ford area and the Spraberry/Wolfcamp areas. In June 2012, all of the counties in the Eagle Ford shale play region and the Permian Basin area experienced drought symptoms that were expressed as “abnormally dry” to “extreme drought” conditions (TX House, 2013). The drought of 2011 in Texas was the hottest and driest year Texas has ever experienced, and no region within Texas was spared (TX House, 2013). West Texas experienced little to no rain during the 2011 year and three major reservoirs in the region, utilized mainly for drinking water purposes, had less than 10% water capacity combined (TX House, 2013). More recent drought afflictions can be seen in *Figure 2.1*, where the north western region of the state near the Spraberry/Wolfcamp formation still has severe water issues, and the region in south Texas where the Eagle Ford play is located is still being affected by drought conditions, although less severe.

The TWDB has analyzed mining water use, which includes oil and gas water use, in a rudimentary manner until the most recent state water plan in 2012 (TWDB, 2012). In 2017, the state water plan will have a more in-depth analysis of calculated projects for mining use within Texas (TWDB, 2012), but this will be rather difficult to account for due to the transient behavior of the oil and gas industry. The importance to plan appropriately for water use in the future is highlighted in the west and south Texas regions where the oil and gas industry will be most active because these regions will have unmet water demands, mainly for irrigation purposes (TWDB, 2012). According to the 2012 State Water Plan, both of these regions will also experience increasing water needs and population levels over the next fifty years (TWDB, 2012). The regional plans have management strategies to meet water needs in the near future, including a large conservation component, and in fact the south Texas region will rely on conservation strategies to supply about 11% of its water needs by 2060 (TWDB, 2012). Water shortages are expected for the oil and gas industry with about 30% of the water needs not being met by 2060, which would cause significant negative economic impacts for incomes, state revenues, and taxes (TX House, 2013). Texas is experiencing unprecedented growth in population and economic opportunities, and without appropriate water resource planning this growth could be hindered by the dwindling water supplies the state has relative to the water demands (TWDB, 2013b).

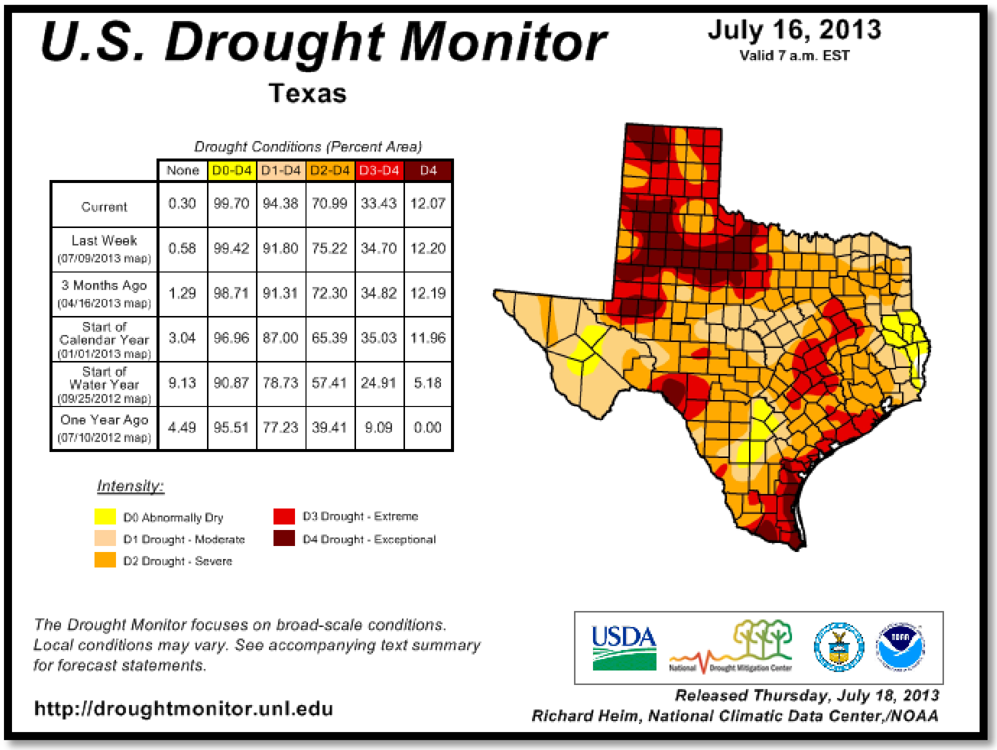


Figure 2.1 – This figure shows a snapshot of the drought conditions across Texas. The drought conditions in Texas were significantly worse in 2011 during the initial stages of the time period for this study (Heim and NOAA, 2013).

According to the 2012 State Water Plan, water users in Texas used groundwater sources for 60% of their needs, including the two regions being assessed in this study. Groundwater is defined as the water percolating below the surface of the earth, and there are two major types of groundwater examined in this study, brackish and fresh water (Steinbach, 2013a). Freshwater is water with TDS amounts of less than 1,000 milligrams per liter of water (TWDB, 2013a). For the oil and gas industry in Texas, groundwater supplies are vital for the operations, especially in the Eagle Ford and Spraberry/Wolfcamp formations. In the Eagle Ford region, over 90% of the water utilized is groundwater, while in the Spraberry/Wolfcamp region, over 75% of the water utilized is groundwater (TWDB, 2012).

The amount of brackish water used in operations is highly variable depending on the operator, for example, one operator has stated ConocoPhillips has “about 60% of brackish water use in the Eagle Ford region” (Strause, 2013). According to a 2012 study released by the Bureau of Economic Geology (BEG), brackish water use by the oil and gas industry was about 30% in the area where the Spraberry/Wolfcamp formations are located, while approximately 20% of the water used by the industry was brackish in the Eagle Ford region (Nicot, et al., 2012). The major groundwater aquifers in Texas can be seen in *Figure 2.2.* This study examined the Carrizo-Wilcox Aquifer for the Eagle Ford region and the Edwards-Trinity Aquifer for the Spraberry/Wolfcamp region, which are the two main groundwater sources for the analysis. These two aquifers vary widely across each region and the modeling water planners undergo for each aquifer is vital to understanding the water use and needs within the region (TX House, 2013). Other considerations must be accounted for when assessing a groundwater aquifer’s viability in a region, including the recharge rate for the aquifer and the various types of withdraws the aquifer experiences over time (TX House, 2013).

Water is a major element for the oil and gas industry and must be consistently factored into each well. Water is a huge cost to the oil and gas industry, and can account for about 25% of the costs an operator incurs for a well, including transportation and waste disposal (Truskowski, 2013). For every barrel of oil there are approximately twelve barrels of water utilized to extract that resource (Savage, 2012). Therefore, operators have incentive to carefully design a successful hydraulic fracture job to control the cost of the well, minimize wastewater byproducts, to maximize production and profits, and to protect the well and formation where resources are being extracted (Savage, 2012). Operators are consistently looking for new and more efficient ways to extract resources like the two in this analysis.

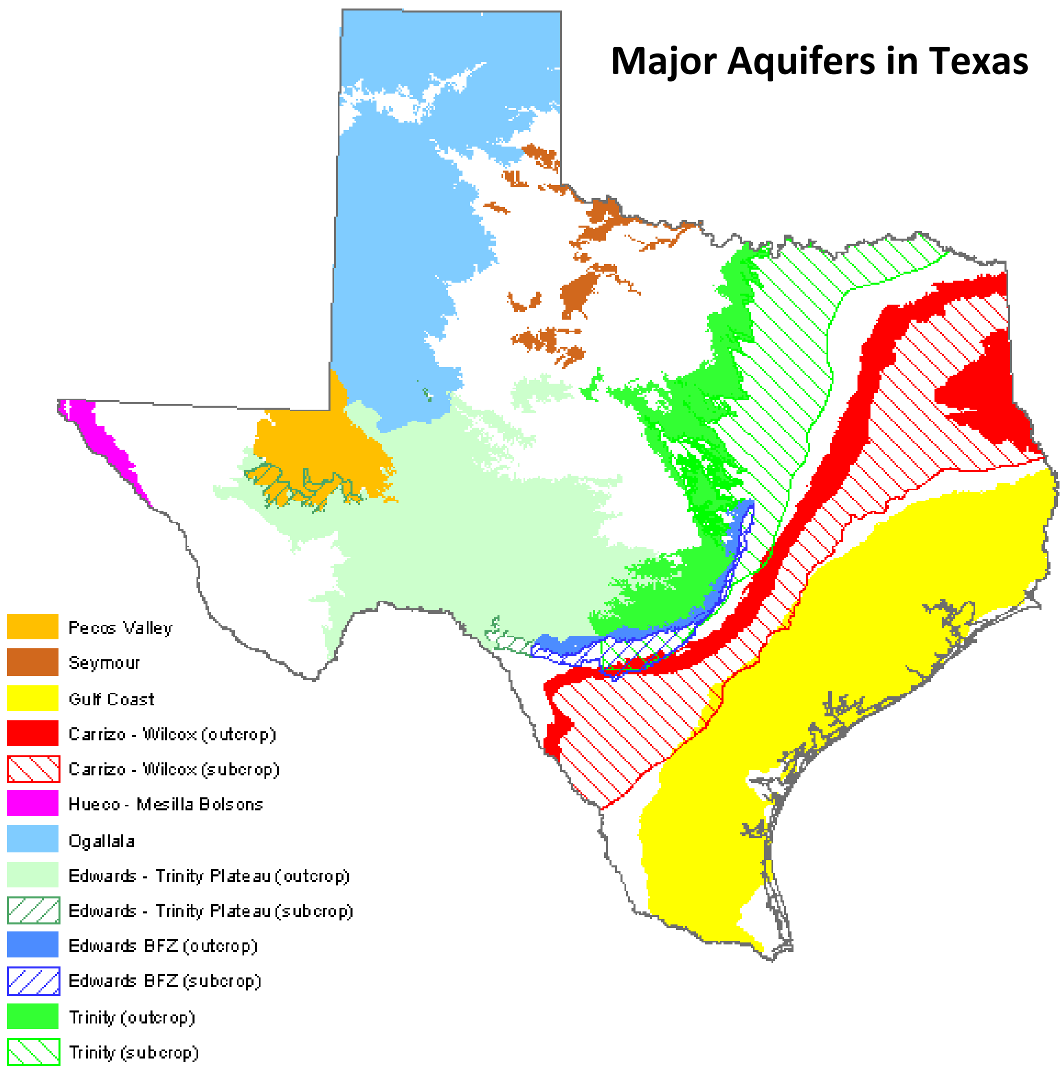


Figure 2.2 – This map displays the major aquifers within Texas, including the Carrizo-Wilcox and the Edwards-Trinity Plateau aquifers (TWDB, 2012).

2.2 Overview of Water Regulations and Water Planning in Texas

Another key component to the structure of water use in Texas is the entities that regulate and plan for Texas water needs. Water planning in Texas is complex and requires coordination and collaboration between local, regional, and state entities. Groundwater regulating entities will be the focus of this analysis, due to groundwater being the major source of water that the oil and gas industry uses for operations in the south and west Texas regions. Texas groundwater law is based on the "rule of capture," implying that a person owns any groundwater that can be drilled within the property boundaries. Some refer to this as the "law of the biggest pump," and the laws protecting this basic groundwater right in Texas have been consistently withstood several court rulings (Steinbach, 2013b).

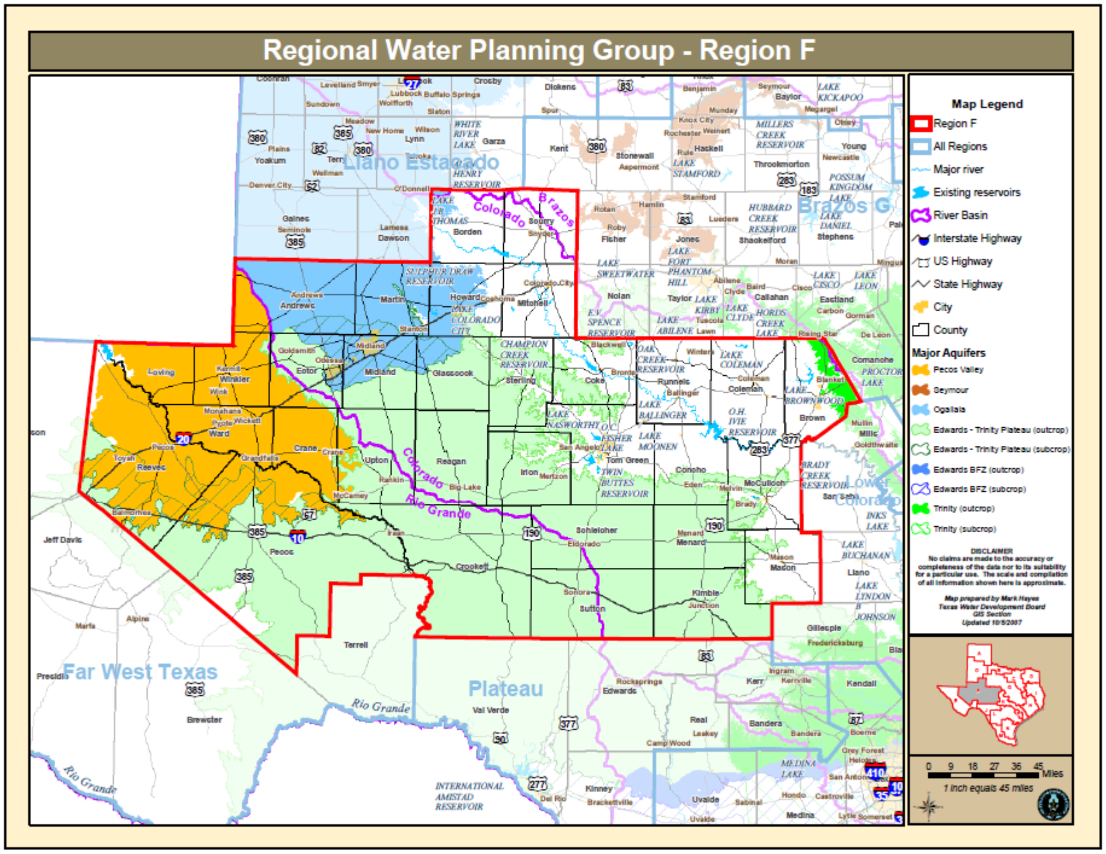
The Texas Water Development Board (TWDB) is a state agency that assesses the state water issues and promotes water development projects to supply the water needs of the state over time (TWDB, 2012). This entity must assist in projecting different water usages over time including mining use, which contains the water use component from oil and gas operations. Every five years this entity releases a state wide water plan that produces solutions to the water issues in different regions of the state and also contains an analysis on each water use, including mining, in the different planning regions (TWDB, 2012). TWDB provides loans and funding for state water projects, and is generally not regulatory in nature (Steinbach, 2013b). The TWDB oversees the state water plan and provides groundwater expertise by approving local management plans and modeling, The TWDB assists each region in modeling for (Steinbach, 2013b):

- Groundwater Availability Models (GAMs),

- Modeled Available Groundwater (MAG), or the amount of water that may be produced on an average annual basis to achieve a desired future condition (DFC),
- Groundwater quality monitoring,
- And, groundwater level monitoring.

This assistance is a joint planning structure and regional water planning a substantial factor and must be considered (Steinbach, 2013b). DFCs are updated at least every five years for “relevant” aquifers, which are aquifers that have groundwater production from them and are managed by local water regulators (French, 2012). These major aquifers include nine major aquifers and twenty-one minor aquifers, including the Carrizo-Wilcox and the Edwards-Trinity aquifers (French, 2012). The TWDB works with local and regional entities to ensure that accurate estimates of MAG are available in the planning process for future water resources (French, 2012). Accuracy in these models that display groundwater availability in an area are vital to understanding future needs and water user needs in the upcoming fifty years in Texas. Recent projections that TWDB had for the mining water use were not as accurate as perceived (Nicot, et al., 2012). The changing economics of the oil and gas industry, the rapid movements of wells and water use, and the vast amounts of HF occurring are several causes for the lack of accuracy for the projected mining use. With the drought adding to the regional water issues, the role of the TWDB must be considered in this study due to the large impact it has for many different water planners and policymakers.

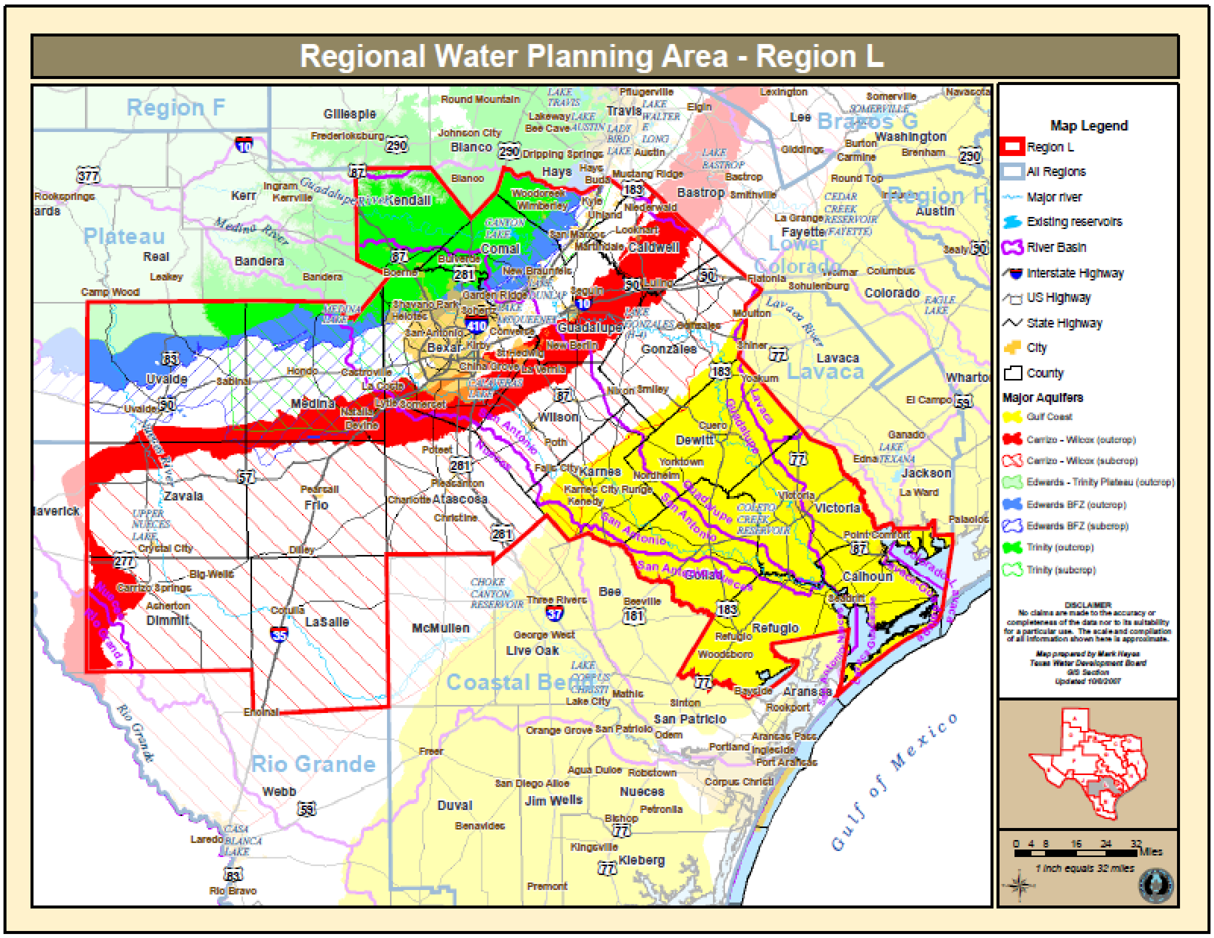
There are sixteen different regions of water planning that the TWDB assesses and gathers data from in the years prior to releasing a state water plan. The two regional water planning entities this study focuses on are Region F and Region L, which are located in west Texas and south Texas, respectively. *Figure 2.3* shows Region F’s overview of planning for the west Texas region, including the aquifers that lie in the region. *Figure 2.4* shows an overview of water planning Region L in south Texas and includes a majority of the Eagle Ford shale play within its boundaries.



Map updated by Mark Hayes, Texas Water Development Board, Planning Division, GIS Section (10/07) L:\projects\RIO\TS\carchuleta\Maps_ArcGIS\MXDs\Regional Water Planning Area Maps

Figure 2.3 – This map shows the water planning Region F, which includes a majority of the Spraberry/Wolfcamp area within its boundaries (TWDB, 2012).

The regional and local regulations of water also include Groundwater Management Areas (GMAs) and Groundwater Conservation Districts (GCDs). Each GCD has the capability to place rules and reporting processes for the oil and gas industry concerning drilled water wells. Since the GMAs and GCDs are relatively small compared to the physical boundaries of the Eagle Ford and Spraberry/Wolfcamp formations, a wide variation on the rules and requirements by these local entities exists (Porter, 2013). *Figure 2.5* shows over 99 confirmed GCDs in Texas as well as showing the areas where GCDs don't exist. For this particular study, most of the areas in the Eagle Ford region have GCDs, while some counties in the Spraberry/Wolfcamp formation area do not have a GCD, like Midland and Upton counties.



Map updated by Mark Hayes, Texas Water Development Board, Planning Division, GIS Section (10/07) L:\projects\RIO\TS\carchuleta\Maps_ArcGIS\MXDs\Regional Water Planning Area Maps

Figure 2.4 – This map exhibits water planning Region L in south Texas and includes a large portion of the Eagle Ford shale play within its planning boundaries (TWDB, 2012).

The TWDB and TCEQ manage groundwater withdrawals in certain instances on a state wide basis, but on a more local level Groundwater Conservation Districts (GCDs) manage withdrawals within their areas (Savage, 2012). In 1997, Senate Bill 1 deemed GCDs are Texas's "preferred method of groundwater management" (Steinbach, 2013b). A GCD is "granted specific legal authority related to the management of groundwater and may regulate things like well spacing and groundwater production," as well as protecting and balancing private property interests (Steinbach, 2013b). To further clarify, GCDs are not municipal water providers, wastewater treatment facilities, nor do these entities own groundwater (Steinbach, 2013b). A GCD has some tax authority on a local level and is created by either the TCEQ or the Texas Legislature (Steinbach, 2013b). Understanding the structure of GCDs reveals various resources these local entities have, as well as the processes GCDs undergo to plan in a district. Most of the board members in GCDs are elected officials, and most of the GCDs have a revenue stream that originates from taxes collected in the locality (Steinbach, 2013b). In the planning process, GCDs must consistently consider aquifer uses and conditions, state water planning, hydrological conditions, private property rights, impacts on subsidence, socioeconomic impacts, environmental impacts, feasibility to achieve DFCs, and any other relevant information when planning (Steinbach, 2013b). The GCD regulates and issues permits for (Steinbach, 2013b):

- Water well spacing,
- Acreage-based regulations,
- And use-based regulations.

When issuing permits, GCDs must manage total groundwater production on a long-term basis to achieve an applicable DFC while considering (Steinbach, 2013b):

- The MAG,
- Exempt use estimates,
- Previously (not permitted) authorized withdrawals,

- Actual production estimates,
- Yearly precipitation,
- And production patterns.

This balancing act between the highest possible level of groundwater production on one side and the conservation, protection, recharging, prevention of waste of groundwater, and control of subsidence on the another side equates to the perfect DFC in a district (Steinbach, 2013b). Some exemptions for permitting requirements exist due to wells specifically exempted by the board, certain domestic or livestock wells, and certain wells related to oil/gas or mining activities (Steinbach, 2013b). In Chapter 36 of the Texas Water Code, a GCD has the authority to require oil and gas operators to register water wells, comply with the rules of the district, and report usage if required (Porter, 2013; TX House, 2013). Due to a section within Chapter 36 of the Texas Water Code, oil and gas users can be exempt from these requirements depending on whether a GCD requires this or not (TX House, 2013).

GCDs currently can issue permits for both fresh and brackish groundwater sources (Steinbach, 2013a). Most GCDs that do distinguish freshwater from brackish water do so by assessing TDS concentrations, as defined within this study, but it is not common for this distinction to occur, nor is it common for a difference between the two types of groundwater to be identified in groundwater models that water planners utilize (Steinbach, 2013a). GCDs could potentially incentivize production of higher concentrated TDS or other unutilized groundwater through rules that distinctly identify the brackish water zones within the district's boundaries (Steinbach, 2013a). Many think defining brackish water solely by TDS concentrations is a rudimentary way to determine the "usability" or "desirability" of the water source (Steinbach, 2013a).

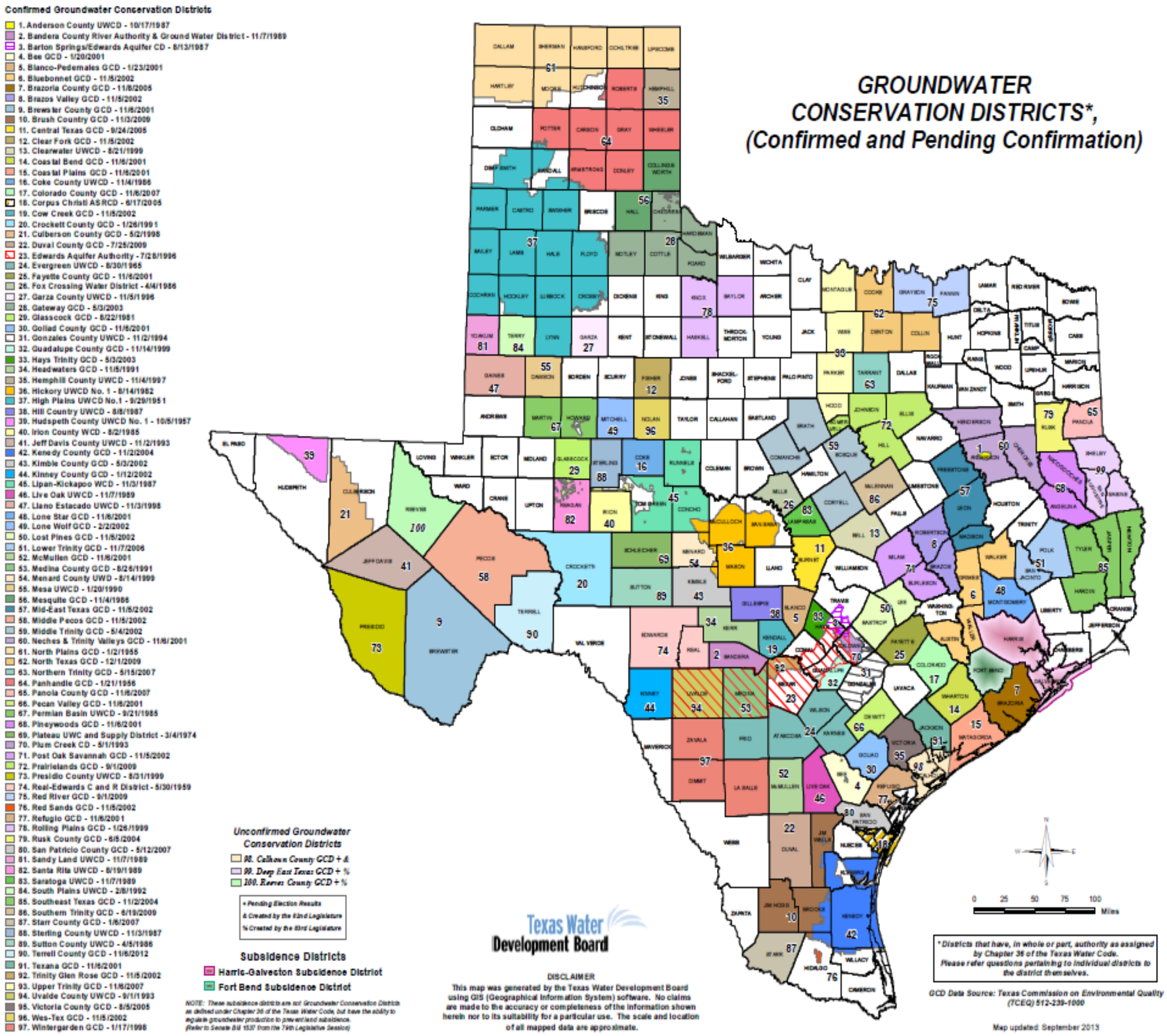


Figure 2.5 – This map displays the multitudes of Groundwater Conservation Districts (GCDs) in Texas. There are many GCDs within the Eagle Ford shale play boundaries and the Spraberry/Wolfcamp formation boundaries (TWDB, 2012).

2.3 Local Water Use

Although mining water use is only 1% of the state's total water use currently, the need to assess impacts that the oil and gas industry has on more localized regions has been expressed by several entities (Nicot, et al., 2012). More than half of the water used in Texas is groundwater and 85% of that groundwater lies within a GCD (Steinbach, 2013b). Mostly reigning over rural regions, the largest users that the GCDs have to deal with are municipal and agriculture users, while less than $1/10^{th}$ of the time the oil and gas industry are the largest users within a GCD, equating to approximately ten GCDs (Steinbach, 2013b). In some areas, the water use for mining can be a large percentage, even accounting for 30% of Dimmit County's 2011 water use, as can be seen in *Table 2.1*. This study does both a regional assessment of west Texas and south Texas, specifically in the areas where the Eagle Ford and the Spraberry/Wolfcamp formations are located, and it also incorporates an analysis on six counties in the two regions. *Table 2.1* shows the changes in water use from 2010 to 2011 in these six counties. The largest changes in water use, especially for mining and irrigation can be seen in the south Texas counties. The largest growth of water use in the three counties assessed for the west Texas region was attributed to the municipal users in Midland County.

Table 2.1: Texas County Water Use					
South Texas: De Witt County	**2010**		**2011**		**Growth**
Municipal	998,407,464	59.38%	1,328,494,527	42.04%	-17.34%
Manufacturing	59,956,584	3.57%	78,855,942	2.50%	-1.07%
Mining	20,854,464	1.24%	709,377,627	22.45%	**21.21%**
Livestock	550,362,339	32.73%	847,212,600	26.81%	-5.92%
Irrigation	51,810,309	3.08%	195,836,451	6.20%	3.12%
De Witt County Total	*1,681,391,160*		*3,159,777,147*		
South Texas: Dimmit County					
Municipal	834,504,411	17.39%	782,042,400	19.68%	2.29%
Mining	326,828,553	6.81%	1,208,255,508	30.41%	**23.60%**
Livestock	179,869,752	3.75%	151,520,715	3.81%	0.06%
Irrigation	3,457,604,961	72.05%	1,831,934,322	46.10%	-25.95%
Dimmit County Total	*4,798,807,677*		*3,973,752,945*		
South Texas: Gonzales County					
Municipal	1,338,595,908	30.90%	1,574,837,883	23.66%	-7.25%
Manufacturing	782,042,400	18.05%	691,781,673	10.39%	-7.66%
Mining	9,123,828	0.21%	732,187,197	11.00%	**10.79%**
Livestock	1,776,865,503	41.02%	1,438,306,314	21.61%	-19.42%
Irrigation	424,909,704	9.81%	2,219,697,012	33.34%	23.54%
Gonzales County Total	*4,331,537,343*		*6,656,810,079*		
West Texas: Glasscock County	**2010**		**2011**		**Growth**
Municipal	58,979,031	0.34%	53,439,564	0.29%	-0.05%
Mining	1,629,255	0.01%	664,736,040	3.67%	**3.66%**
Livestock	75,597,432	0.44%	62,237,541	0.34%	-0.10%
Irrigation	17,032,883,472	99.21%	17,351,565,750	95.70%	-3.51%
Glasscock County Total	*17,169,089,190*		*18,131,978,895*		
West Texas: Midland County					
Municipal	10,612,315,368	42.96%	10,772,634,060	57.48%	14.52%
Manufacturing	53,439,564	0.22%	52,136,160	0.28%	0.06%
Mining	220,601,127	0.89%	926,394,393	4.94%	**4.05%**
Livestock	294,569,304	1.19%	87,328,068	0.47%	-0.73%
Irrigation	13,520,535,543	54.74%	6,902,175,882	36.83%	-17.91%
Midland County Total	*24,701,460,906*		*18,740,668,563*		
West Texas: Upton County					
Municipal	306,951,642	4.58%	345,076,209	6.06%	1.48%
Manufacturing	-	0.00%	39,753,822	0.70%	0.70%
Mining	867,415,362	12.94%	714,591,243	12.54%	**-0.40%**
Livestock	69,080,412	1.03%	33,236,802	0.58%	-0.45%
Irrigation	5,460,936,909	81.45%	4,565,172,510	80.12%	-1.33%
Upton County Total	*6,704,384,325*		*5,697,830,586*		
(Source: TWDB, 2013)					

There are two GCDs that are important to note for this analysis, including the Wintergarden GCD in the Eagle Ford shale play and the Glasscock County GCD in the Spraberry/Wolfcamp region. The Wintergarden GCD was created in 1997 and has oversight in three counties in south Texas, including Dimmit, LaSalle, and Zavala (WGCD, 2013). The Wintergarden GCD is actively researching with other entities about different groundwater issues within the three counties (WGCD, 2013). Most of the Eagle Ford region lies within a GCD except for a few outline counties on the boundaries of the shale play. The GCDs in the Spraberry/Wolfcamp region do not cover the entire area of the plays in the region, excluding two major counties, Midland and Upton. The Glasscock GCD was formed in 1981 and consists of Glasscock county and portions of northwest Reagan county (GGCD, 2013). Most of the use within this district comes from agriculture users (GGCD, 2013). The requirements that these two GCD's have for the oil and gas industry are minimal and planning within each district lacks a robust analysis of local impacts the oil and gas industry may introduce in the area.

Water use by the oil and gas industry has been of concern on the local level in part because there are only a limited number of water resource options (Bertetti and Green, 2013). For example, the Eagle Ford's only water resource option in the vicinity is the southwest portion of the Carrizo-Wilcox Aquifer (Bertetti and Green, 2013). As can be seen in *Table 2.1* water use for the mining category in Dimmit and De Witt counties has grown over 20% from 2010 to 2011, while Gonzales experienced an expansion of over 10%. The drought that Texas is experiencing only amplifies water issues in the region, and it is important to understand the various aspects of this complex issue.

2.4 Recycling/Reuse of Flowback Water

Fluids that return post a HF event are called produced water or flowback water, and the potential for these fluids to become an option as a source of water in the oil and gas industry is becoming more evident. Texas does not see much recycling or reuse within its boundaries though (Nicot, et al., 2012). The Midland Basin, where the Spraberry/Wolfcamp formations are located only about 2% of the water utilized for oil and gas operations originate from recycling and reuse (Nicot, et al., 2012). And the Eagle Ford shale play has little to no recycling of flowback water (Nicot, et al., 2012).

There are some challenges associated with recycling and reuse of flowback water. State regulations at times hinder the development of new technologies that can utilize on-site recycling or other reuse techniques. Recently the RRC has encouraged more recycling by the industry through modifications of particular restrictions within internal regulations (RRC, 2013a; Savage, 2013). The rule modifications specifically authorize certain on-lease non-commercial recycling for hydraulically fractured flowback fluids, and also clarified permitting requirements for commercial or centralized recycling of flowback fluids (Savage, 2012). Recycling and reuse of flowback water have some challenges associated with it beyond just the regulatory obstacles. Specifically for fluids that return post a HF event, not all these fluids flowback at once and between 10% and 75% of the fluids will flowback within the year following the event (Nicot, et al., 2012; Wythe, 2013). Not only does the flowback of the fluids vary by time, but also there will be impurities, including minerals, oil, salt, and other constituents, within the flowback fluids that must be filtered before reuse (Wythe, 2013). The technologies to filter these constituents can be both expensive and difficult to bring and utilize on an oil and gas well site, some have energy requirements and necessitate storage of the flowback fluids (Malewitz and Satija, 2013).

Liability issues associated with this can further hinder a company's motivation to recycling and reuse water. A final difficulty to overcome for industry operators will be the variations in flowback fluid constituents and difference in each play will have to be accommodated for. Over time these challenges can be overcome within the industry with advances in technology and collaboration between industry and regulators (Wythe, 2013).

There are benefits to recycling and reuse of flowback water that will become more pronounced as these practices become more abundant in Texas. For operators, the costs of hauling in millions of gallons of water on to a well site will be reduced significantly, if not eliminated (Halliburton, 2013). The costs of the technologies used to implement recycling will decrease as the practices become more robust and the technologies are utilized by more operators. Recycling and reuse not only incorporate some areas of cost reductions, but it also provides a sense of "social responsibility" for operators. The creation for a market for the treated water beyond just the oil and gas industry uses could prove to be beneficial for both the area and the oil and gas operator selling the water post the initial use (Malewitz and Satija, 2013). The benefits for recycling and reuse will continue to motivate the oil and gas industry in Texas.

Recently, some operators have overcome the previously described challenges and are actively utilizing recycling and reuse techniques to optimize operations and reduce water usage in the regions where upstream development of oil and gas resources are occurring. Although, in Texas, there are over 10,000 disposal wells that the oil and gas industry utilizes for waste disposal, and this cheap method is easily accessible for many operators (Savage, 2012). Recycling is not abundant within Texas, and so far in 2013, there have been a limited number of permits for oil field recycling activities, although this does not account for mobile recycling units which are more feasible in the rural locations that the Texas oil and gas industry operates at

(Malewitz and Satija, 2013; Nicot, et al., 2012). Water recycling is less practical in the Eagle Ford due to the need to move the water over relatively long distances between well sites (Malewitz and Satija, 2013). Specifically for the south and west Texas regions, infrastructure challenges, reliability on the technology, disposal of solid wastes, and the transportation issues are all obstacles that must be overcome for recycling and reuse to become more abundant (TX House, 2013). Texas operators will continue to increase the recycling and reuse operations in the Eagle Ford and Permian Basin as recycling and reuse becomes a more efficient on-site tool in each area.

Recycling and reuse of flowback water are not the only developing technologies that are occurring in the oil and gas industry. In fact there are several different alternatives to HF with water as the main component, and some companies are utilizing these techniques to reduce their water use on well sites. Many companies are combining recycled water and brackish water to meet their needs for oil and gas development processes (Apache, 2013; Driver and Wade, 2013). For example, Apache Corporation in the Wolfcamp shale formation is recycling 100% of its flowback water as well as utilizing brackish water for other HF events in the region. Not only is recycling and reuse of flowback water trending in some regions and with some operators, using alternatives to water to produce fractures are also trending. Waterless "fracking" utilizes different ingredients like liquefied petroleum gas (LNG), gels, or propane to induce the fractures needed during the process that releases oil and gas to the wellbore from the formation pay zone (Wythe, 2013). And although these alternatives to water are more expensive and have technological hurdles, there is potential in the future for a reduction of needs for new water sources or the use of water at all.

Chapter 3: Review of Other Studies

3.1 Bureau of Economic Geology Mining Water Use Report

There have been several significant studies in the recent past that assess water use related to oil and gas operations in Texas. To gather a sense of what research has been done, this investigation will highlight these studies and the different entities examining this complex issue. The first study to summarize was conducted by Nicot, et al. (2012), and has accomplished the most extensive research on the oil and gas industry's water use in the state of Texas due to TWDB support, access to an extensive private database, and an in-depth analysis of the entire state's mining water use. Nicot's, et al. (2012) mining report findings included estimates of county-level water use in 2008 in Texas and projections of water use for these counties to 2060. Looking at both a state level and a regional level based on active oil and gas plays in Texas, this study assessed that Texas has enough water to accommodate the oil and gas industry needs. Nicot, et al. (2012) indicated that mining water use numbers on a more localized level could be a higher percentage of that area's total water use; therefore mining could potentially have a greater impact on that area. The Nicot, et al. study (2012) had access to a highly elaborate database on water use of the oil and gas industry, allowing for the analysis to be complex and more substantial than most, thereby creating more ways to analyze the data beyond just water volume trends including the three major ratios listed below:

- Water Use Intensity (gallons/foot) – the total volume of fluids used per a linear foot of the fractured well
- Proppant Loading (pounds/gallon) – the total mass of proppant per a volume of HF fluids
- Proppant Intensity (pounds/foot) – the total mass of proppant per a linear foot of the total fractured well depth interval

The Nicot, et al. (2012) mining report mentions that data beyond the database about water sources, including information from industry and other stakeholders, was significantly difficult to attain because the lack of records of water source and use tracking for the oil and gas industry.

The Eagle Ford shale play numbers in this study showed a unique outcome of increased activity in the region from 2011, but a decrease in water use intensity over the last four years by approximately 50% to about 850 gallons per a foot in 2011 (Nicot, et al., 2012). This water use intensity decreased most likely occurred from an industry switch in operational changes from water intensive HF jobs, like slickwater jobs, to less water intensive fracturing events with gel fractures (Nicot, et al., 2012). A slickwater job has more water and contains friction reducing components, while the gel fracture jobs have less water and can be used in particular areas where geological attributes of the formation need better transportation of the proppant material. This report also found about 1/5 of the water being utilized in the Eagle Ford area to be brackish, but noted that this amount is variable between operators (Nicot, et al., 2012). Nicot, et al. (2012) projects that water use intensity for the Eagle Ford shale play will increase over the next ten years, peak and then slowly begin to decrease, potentially due to decrease in activity in the region, better technologies, and reduction of water use with existing technologies.

The study also assessed the Permian Basin area, including the Midland Basin, which contains the Spraberry/Wolfcamp formations. The study assesses the Wolfberry trend noticing that the vertical length of the pay zone, or productive section with the formation, has increased in the recent years (Nicot, et. al, 2012). The longer vertical length contributes to the increased water use intensity this area is seeing to about 400 gallons per a foot (Nicot, et. al, 2012). Also, the number of horizontal wells has been increasing in the Wolfcamp shale play, adding to an increased water use average per a well to approximately one million gallons per a well (Nicot, et.

al, 2012). The water use intensity changes significantly between the Spraberry and Wolfcamp formations, and the horizontal drilled Wolfcamp has close to 2.5 times more water use intensity than the vertically drilled Wolfberry area (Nicot, et al., 2012). According to this study, the oil and gas industry in the Midland Basin area utilizes about 68% of fresh groundwater to fulfill its operational needs (Nicot, et al., 2012). Development in the Wolfcamp is highly likely to continue to increase and water use within the region may be variable in the future due to changes in recycling and reuse techniques or non-freshwater use (Nicot, et al., 2012). Recycling and brackish water are expected to significantly increase between now and 2060 in the Permian Basin (Nicot, et al., 2012).

3.2 Texas House Interim Report

The second major study was an interim report to the 83rd Texas Legislature issued by the Texas House of Representatives Committee on Natural Resources in January 2013 that contained a major assessment on the complex relationship between water and energy resources and the needs in Texas, including water quantity impacts by the oil and gas industry. Addressing the growing energy-water needs Texas has, this report brought together many different stakeholders to comment on the arising issues Texas will face. The report highlights the recent drought and reports that mining use for the state is expected to increase by 2060 to approximately 9% of the state's water use total (TX House, 2013).

The Interim Report by the Committee on Natural Resources (2013) found that of the approximately 4,000 wells drilled in the Eagle Ford, there was a water demand that ranged from 85,000 barrels to 100,000 barrels (TX House, 2013), which is equivalent to 3,570,000 gallons to 4,200,000 gallons of water. The demand for water in the area by the oil and gas industry is expected to be between 5% and 7% of the total water use for the Eagle Ford region (TX House, 2013). This report had an example of an oil and gas operator that has completed and is producing from 177 wells in the Eagle Ford shale play with an average of 4.95 million gallons per a well (TX House, 2013). The Texas House report (2013) also stated that in 2012, over 3,000 well permits had been issued for the Eagle Ford shale play area and approximately half of those wells were drilled using an average of 6.1 million gallons per well. This equates to approximately 9 billion gallons of water used in total for 2012 for that area (TX House, 2013). The diverse average water volumes per a well this report introduces show that there is a highly variable nature for this issue can create reduced accuracy in water use projections (TX House, 2013). The TX House (2013) projects that over 25,000 more wells will be drilled in the Eagle Ford in the next 20 years. Texas House (2013) also expressed concern over the difficulty in the ability to accurately predict the Carrizo-Wilcox aquifer availability modeling and manage the groundwater supply in the Eagle Ford region. The Interim report (2013) states that the Wintergarden GCD desires to assess that impact that oil and gas operations have on the water supply in the district by determining percentage of water usage versus the rate of recharge for an aquifer, specifically for the Carrizo-Wilcox aquifer. Developing the Eagle Ford shale play, according to this study (TX House, 2013), would require about 1/3 of the average annual recharge for the Carrizo-Wilcox aquifer. The Wintergarden GCD finds that groundwater in the area has been significantly over overdrawn and has been pumped at rates much higher than the annual recharge, for most of the past century long before significant oil and gas operations have been present in the area (Brownlow, 2013; TX House, 2013).

The study also minimally assessed water use by the oil and gas industry in west Texas. The Permian Basin had over 9,300 well permits issued last year, and over half of those were drilled (TX House, 2013). On average each well accounted for approximately 1.9 million gallons of water used per well, equating to approximately 9 billion gallons of water used in the region (TX House, 2013). The interim report had a significantly less robust assessment of the Permian Basin region, specifically toward the Spraberry/Wolfcamp formations. The report included a significant amount of input from experts from different stakeholder groups, including academia, regulatory, and industry experts.

3.3 Eagle Ford Specific Reports

There were two more major studies conducted on the Eagle Ford shale play and water use in the region. A report conducted by the Eagle Ford Task Force, led by RRC David Porter, is a comprehensive overview of the Eagle Ford shale play and includes water quantity issues within the area (Porter, 2013). Following several data analyses and expert recommendations, Porter (2013) concludes that one of the major aquifers in the Eagle Ford area, the Carrizo-Wilcox aquifer, contains enough water to meet the needs of the oil and gas industry along with the other water users in the area. Note that the Carrizo-Wilcox aquifer supplies approximately 40% of the water used in the region (TWDB, 2012). The Eagle Ford task force did also suggest in the report that local impacts on water use may need to be addressed (Porter, 2013). Commissioner Porter (2013) recommended that there should be a continued study of local impacts and water use within the Eagle Ford, and that the industry and policymakers should continue to promote best practices towards water management in the region.

The second major analysis of the Eagle Ford issued by the Southwest Research Institute assessed water use and presented the data at a recent Texas Groundwater Summit (Bertetti and Green, 2013). After an assessment of water use in the Eagle Ford from various stakeholders, there were several estimated numbers the Southwest Research Institute presented showing, like the Texas House Interim Report, that there is a wide variance of estimations on water use numbers for the south Texas region. Two recent estimations on the water use per year in the Eagle Ford ranged from approximately 4.8 billion gallons of water to over 9 billion gallons of water estimated by the RRC (Bertetti and Green, 2013). According to the Wintergarden GCD, water usage in the 2012 for the three counties it oversees, the water use accounted for close to 3 billion gallons of water, and estimates from a reporter of the Texas Observer saw approximations closer to 4.8 billion gallons of water for those three counties in 2012 (Bertetti and Green, 2013). Bertetti and Green (2013) also assessed the Carrizo-Wilcox aquifer in their research, and found that at least ½ of the recharge for the aquifer is estimated to be used for oil and gas operations. The recharge of the aquifer has been less than the withdrawals from the aquifer in the past few decades, and the water level has declined within the aquifer (Bertetti and Green, 2013; Brownlow, 2013). The recharge of the aquifer is dependent on the variable rainfall amounts among other things, but it is apparent that withdrawals from the aquifer are happening faster than the recharge of the aquifer (Bertetti and Green, 2013; Brownlow, 2013).

The robust amount of studies done on water use in the Eagle Ford shale play region shows the lack of specific reports for the Spraberry/Wolfcamp region, beyond the Nicot, et al. study (2012) and the Texas House Interim Report (2013).

3.4 Nonprofit Analyses

Two non-profit organizations, Ceres and the Environmental Defense Fund (EDF), have assessed the water quantity issues that revolve around shale play development specifically. The report issued by Ceres (Freyman and Salmon, 2013), shows growing competition for water, including in Texas where approximately half of the 11,634 wells analyzed were reportedly in “high” or “extremely high” water stressed areas. This report (Freyman and Salmon, 2013) utilized water quantity data of oil and gas operations from the FracFocus database and the water stress region data from the World Resources Institute.

The second study by a non-profit stakeholder (Palacios, 2013), discussed the need to decrease the freshwater use by oil and gas operations in an optimal manner. This report (Palacios, 2013) concluded that there were currently four main counties in the Eagle Ford region that could benefit from a strategic reduction in freshwater use by the oil and gas industry, including Dimmit, Karnes, Live Oak, and Webb counties. Palacios (2013) also pointed out that in 2011 Karnes, DeWitt, and Dimmit counties had about 25% of the total county-wide water demand accounted for from water use by oil and gas operations. And the Palacios study (2013) concludes that by 2020, Webb and Live Oak counties will join the list of counties that have over 25% of the water demand from oil and gas operations. For the Spraberry/Wolfcamp region, Irion county had over 25% of its water use attributed towards the oil and gas industry use (Palacios, 2013). Palacios (2013) shows that two of the ten counties in the west Texas Spraberry/Wolfcamp area were currently a high priority and could benefit from strategic reductions in water use by the oil and gas industry, including both Upton and Irion county. By 2020 Regan County will have close to 25% of its total water use going towards oil and gas developments (Palacios, 2013). These non-profit stakeholder studies are important to capture in this literature review because the insight these studies have in displaying the concerns of this particular group of stakeholders.

3.5 News Reports

The last major source informing on water use are the various news reports on a national, state, and local level. Recognition of the media due to its large audience and wide dispersion of information is important. Although official documents or peer-reviewed articles are not normal in this realm, the news can be just as powerful to several different stakeholders concerned with the water quantity issues, including landowners and other local entities. A variety of articles discuss water quantity issues in the south and west Texas regions, showing the media's influence on the issue, especially on the public. The overview of these studies and stakeholder viewpoints show significant analysis and many different views on this complex dilemma, while also showing several different factors and obstacles involved in the water quantity issues surrounding the Eagle Ford shale play and the Spraberry/Wolfcamp regions.

Chapter 4: Methods

4.1 FracFocus and Sky Truth Databases

For the quantitative study, the data for this study was extracted from two public databases, the FracFocus Chemical Disclosure Registry (FracFocus) and the more accessible and easily downloadable data from SkyTruth, which is a secondary database that also extracts information from FracFocus (GWPC & IOGCC, 2013). As seen in *Figure 4.1*, FracFocus is a national registry with public access to data by downloading individual PDF files for individual well locations, that includes information on the location of the well, water volume, a time period of the HF event, other service companies that are a part of the HF process, and other identification characteristics for that particular well (USEPA, 2012). The FracFocus database does not make a distinction between horizontal and vertical wells.

In 2011, the first year of the FracFocus database's existence, there were over 196 participating companies, 96 reporting companies, and over 12,000 wells reported on the database (Savage, 2012). The activity within this database only continues to increase and due to a recent 2012 requirement in House Bill 3328 by the 82rd Texas Legislature oil and gas operators are required to report to the FracFocus (Savage, 2012). The RRC requires oil and gas operators to report all HF activities to FracFocus and the RRC if the permit for the well occurred on or after February 1, 2012 (Savage, 2012).

FracFocus Disclosure Registry Document Example

Hydraulic Fracturing Fluid Product Component Information Disclosure

Job Start Date:	1/26/2013
Job End Date:	1/30/2013
State:	Texas
County:	Glasscock
API Number:	42-173-35374-00-00
Operator Name:	Pioneer Natural Resources
Well Name and Number:	WEYMAN 15A #2
Longitude:	-101.73507230
Latitude:	31.90733214
Datum:	NAD27
Federal/Tribal Well:	NO
True Vertical Depth:	10,710
Total Base Water Volume (gal):	1,436,064
Total Base Non Water Volume:	0

Hydraulic Fracturing Fluid Composition:

Trade Name	Supplier	Purpose	Ingredients	Chemical Abstract Service Number (CAS #)	Maximum Ingredient Concentration in Additive (% by mass)**	Maximum Ingredient Concentration in HF Fluid (% by mass)**	Comments
Water	Pioneer Natural Resources	Carrier/Base Fluid					
			Water	7732-18-5	100.00000	88.21902	
SAND (WHOLE GRAIN)	Pioneer Natural Resources Pumping Services LLC	Proppant					
			Crystalline Silica Quartz	14808-60-7	99.50000	9.79187	
Silica Sand	Pioneer Natural Resources Pumping Services LLC	hydraulic fracturing/proppant					
			Crystalline Silica	14808-60-7	99.90000	0.56036	
			Aluminum oxide	1344-28-1	0.80000	0.00449	
			Titanium Oxide	13463-67-7	0.10000	0.00056	
			Iron oxide	1309-37-1	0.10000	0.00056	
Hydrochloric Acid, 33-40%	Pioneer Natural Resources Pumping Services LLC	Stimulation					
			Water	7732-18-5	67.00000	0.30392	
			Hydrogen chloride	7647-01-0	40.00000	0.18144	
Santrol Resin Coated Sand	Pioneer Natural Resources Pumping Services LLC	Proppant					
			Crystalline Silica (quartz)	14808-60-7	97.00000	0.35824	

Figure 4.1 – This figure displays the form that data extracted from the FracFocus database was presented in. For the data is able to be downloaded by individual PDF documents presented in this format (GWPC & IOGCC, 2013).

The SkyTruth database utilized in this analysis is a secondary database that extracts PDF files from the FracFocus database and inputs these files into easily downloadable documents (SkyTruth, 2013). Extracting data from FracFocus directly is time consuming, has more potential for human error, and does not allow for easily accessible and flexible data. The SkyTruth database, allows for easy downloading for data extracted from FracFocus and is compiled into a format that allows for flexibility and reduction in time to gather data. This study compared the difference of approximately 2,500 wells in the Eagle Ford region between the data extracted from the FracFocus database to the SkyTruth data and showed that there were no significant differences of the average trends of water use, therefore the utilization of the SkyTruth data for the larger analysis of the Eagle Ford shale play and the Spraberry/Wolfcamp regions is feasible in this study. This analysis is assessing data from the beginning of the FracFocus database in January 2011 through May 2013.

4.2 Qualitative Analysis

This study conducted two different analyses, one qualitative and one quantitative. The qualitative approach assesses the complex stakeholder involvement of the issue by utilizing a collaborative approach. This approach utilized input from various stakeholders as well as a holistic review of the complexities surrounding the issue to identify key trends and further areas of assessment for water planners and the oil and gas industry in the west and south Texas regions. This approach was implemented by reaching out to various stakeholders to gather a more extensive understanding of the different perceptions of this intricate and dynamic subject. The specific stakeholders that had significant contribution to this study include:

- Oil and gas industry representatives from ConocoPhillips,
- Water industry professionals from the American Water Works Association (AWWA), including a Colorado water utility with significant interest in the oil and gas industry within the utility's boundaries,
- Local perspectives in the Eagle Ford shale play area, including a landowner with a strong background in hydrology and Texas water planning,
- Federal regulators from the USEPA that are conducting the water acquisition component of the USEPA HF study,
- FracFocus database owners and operators,

- Legal professionals involved in the issue in Texas,
- Academia and research group entities
- Regulatory professionals, both state and local, including a RRC representative, TWDB representative, and a state-wide GCDs representative,
- And, representatives involved in the policy-making process, including assistants to Texas House representatives.

If personal communication with the stakeholders was not accessible, this analysis gathered information made publically available, including oil and gas company investor presentations and conference presentations. The qualitative analysis strived to find a holistic and accurate representation of water use trends in the regions and provide perspective on what multitudes of entities are doing to assess this intricate issue.

4.3 Quantitative Analysis

The SkyTruth database was not as up-to-date as the FracFocus database, and had only downloadable data through April 2013. The FracFocus data directly extracted for this study is utilized to examine potential trends within three different counties in the Eagle Ford region through May 2013, including DeWitt, Dimmit, and Gonzales. DeWitt and Dimmit counties were chosen for further analysis due to the location of each county in a core zone of activity for the Eagle Ford shale play (Nicot, et al., 2012). Gonzales County was chosen to introduce a county that has activity, but is not in a core zone of activity for the shale play. The Sprayberry/Wolfcamp counties analyzed were Glasscock, Midland, and Upton counties. Glasscock and Upton counties were chosen due to the major oil and gas activity the counties have (Nicot, et al., 2012), while Midland county was chosen as a county that has less activity from the Spraberry/Wolfcamp formation. The data for both the regional analysis and the county analysis for the Spraberry/Wolfcamp area were extracted from SkyTruth. The data analyzed within Sky Truth is available from January 2011 to April 2013, while data utilized from FracFocus directly goes from January 2011 through May 2013 for the individual county analyses of the Eagle Ford. The FracFocus database has water volume in gallons of each hydraulically fractured job (GWPC & IOGCC, 2013). If there was a discrepancy between the database and reality of which county the well may be located within, that well was deemed an outlier and eliminated from the analysis.

The regional analysis of the Eagle Ford shale play incorporated over 5,000 data entries from 21 counties, including Atascosa, Austin, Bee, Brazos, Burleson, DeWitt, Dimmit, Fayette, Frio, Gonzales, Grimes, Karnes, LaSalle, Lavaca, Lee, Live Oak, Maverick, McMullen, Webb, Wilson, and Zavala counties (SkyTruth, 2013). The regional analysis for the Spraberry/Wolfcamp region integrated above 7,400 data entries from 10 counties, including Andrews, Dawson, Gaines, Glasscock, Howard, Irion, Martin, Midland, Reagan, and Upton (SkyTruth, 2013). To reduce the amount of human error and to eliminate any outliers that could skew the data, this study analyzed data between the 5th and 95th percentiles. The average trend analyses conducted in Microsoft Excel. The equation utilized to calculate the average trends for each region and the each of the six individual counties can be seen below:

$$Average\ Water\ Use = \left(\frac{x_1 + x_2 + \cdots + x_n}{n}\right)$$

where, n is the total number of wells within the 5th and 95th percentile of the area and x is the water volume utilized per each well.

The data for different operators was less robust and the number of entries within the FracFocus database varied drastically for each operator and over time. Also, some operators sold operations to other operators between January 2011 and April 2013. Therefore, although there are several major operators in both south and west Texas, the average trend analysis for the companies was not applied. Assessing company trends in this investigating lacks empirical evidence to statistically verify the trends and therefore the company analysis component of the study is problematic and needs more data entries.

4.4 Data Limitations

The FracFocus database was publically accessible to for individuals to access information input into the database voluntarily, until recently in Texas. Originally, the FracFocus database was based upon voluntary input from operators in the Texas from January 2011 to January 2012 (Porter, 2013). After the 82nd Texas Legislature passed the law requiring disclosure, the RRC mandated that all companies operating in Texas must report to the database and also send a copy of that to the RRC starting in February 2012 (Porter, 2013; Savage, 2012). Another change to the FracFocus database occurred officially in June of 2013, when the database system switched from the original system to a 2.0 database framework (GWPC & IOGCC, 2013). The 2.0 system for FracFocus included more validation and checks for errors during the data input process, thus reducing human error (GWPC & IOGCC, 2013). The analysis this study implements is utilized to reduce some bias from outliers that unseen errors in the data could create due to the lack of data validation during the input process prior to June 2013. For example some operators may accidently report water volume in number of barrels rather than gallons, or an operator may accidently input the wrong number or miss a number in the water volume field within the FracFocus database.

Chapter 5: Results and Discussion

5.1 Qualitative Analysis

Discussions with different stakeholders and a literature review analysis were conducted throughout the course of this research. Conclusively, the estimations for water use in both regions were highly variable and consensus that most water sourced in both the south and west Texas regions were mostly from fresh groundwater sources. There is a slight trend in both regions towards brackish water use (Strause, 2013). And there are also recycling and reuse projects that are occurring in both regions, but wide scale recycling and reuse are not occurring currently (Nicot, 2013; Malewitz and Satija, 2013).

5.2 Regional Results

The average water use trends of the Eagle Ford region, using data from 2011 to end of April 2013 shows an increase in the average amount of water used per HF event at a well, as seen in *Figure 5.1*. The Eagle Ford region on average used approximately five million gallons of water per a HF event from 2011 to April 2013. Previous studies show a shift by the oil and gas industry from more water intensive fracturing jobs to less water intensive jobs (Nicot, et al., 2012). *Figure 5.1* exhibits the average trends of the Spraberry/Wolfcamp region using data from 2011 to end of April 2013 and shows an increase in the average amount of water used per HF event at a well. The west Texas region on average used approximately 900,000 gallons of water per a HF event from 2011 to April 2013.

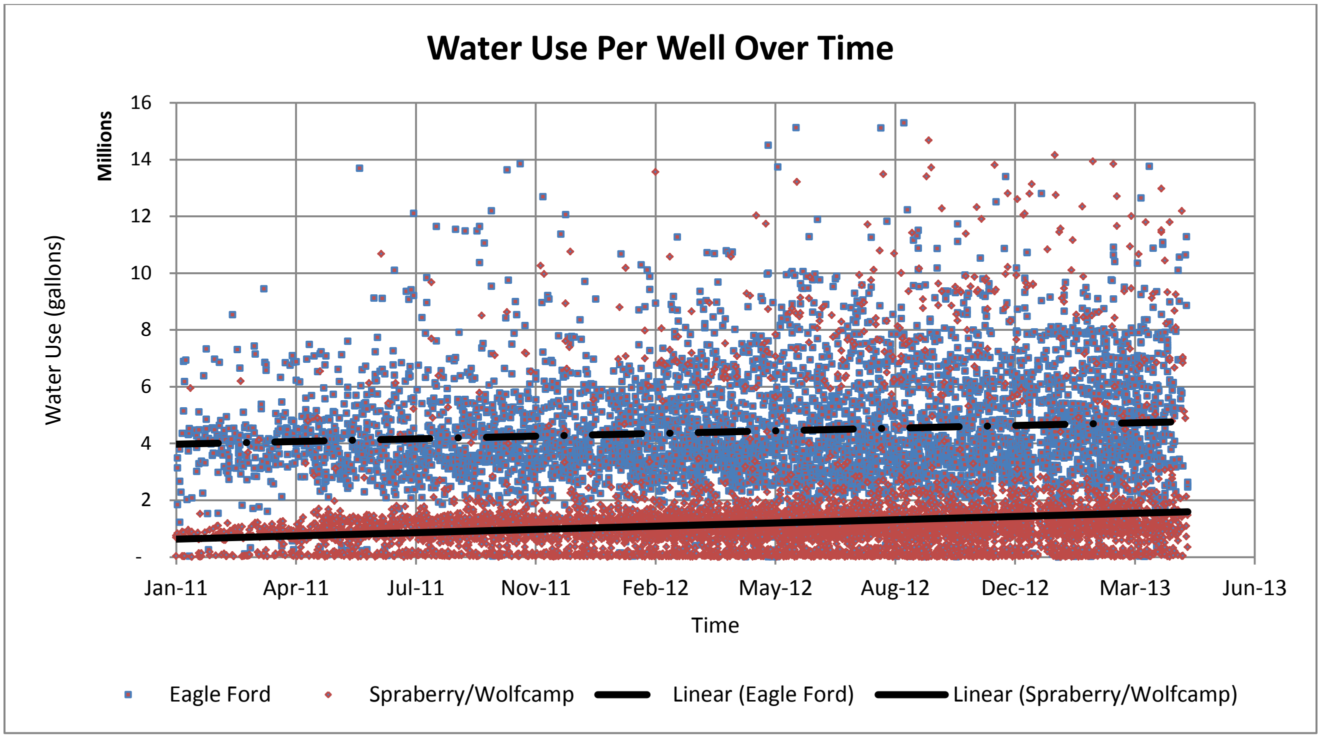


Figure 5.1 – This graph displays water use per well over time in both regions analyzed in this study.

Both the Eagle Ford region and the Spraberry/Wolfcamp region showed an increase in average water use between January 2011 and April 2013. The overall average for the Eagle Ford region at about 5 million gallons per a well is significantly higher than the Spraberry/Wolfcamp area of the approximately 900,000 gallons per a well. The difference in average water use in each region can be attributed to the fact that horizontally drilled wells utilize more water than vertical drilled wells during the HF process (Bai, et al., 2013; Bertetti and Green, 2013). The Spraberry/Wolfcamp is abundant with many opportunities for resource extraction with vertical drilling within the "stacked" plays due to large intervals of pay zone, especially in the Spraberry, but horizontal drilling in the Wolfcamp area will increase (Pioneer, 2013b).

A comparison of the two regions can be seen in *Table 5.1*. The table displays that the two regions are different in area, number of wells, and water use per a well. The quantitative data utilized within this study allowed for assessing the average water use per a well, but the trends seen by the water use per well can be misleading. To better understand each region's water use by the oil and gas industry key information will be required. The information required includes identifying the direction of a well, lateral length of a well, and the mass of proppant used during the HF event. The FracFocus database has significant gaps in data collected from operators and service providers in the oil and gas industry. FracFocus was originally created as platform for operators to disclose chemicals and other components being introduced during the HF event at a well (GWPC and IOGCC, 2013). Although substantial changes have occurred to the way data is being reported within the system, the type of data that is being reported has not been modified (GWPC and IOGCC, 2013). The data "gaps" in the FracFocus database of well direction, lateral lengths in wells, and proppant mass reduce the ability to evaluate how water use within a region is moving. A change in water use per a well could imply changes in operator efficiencies, lateral length of wells, direction of wells, or a different factor.

The qualitative assessment and review of previous studies for both areas help understand the water use per a well trend, but do not allow for a completed analysis of how water use by the oil and gas industry can produce significant local impacts. Having data to create water use intensity and proppant loading ratios will form a more holistic view for this evaluation. Many water planners do not have access to robust and private data sets required to examine water use impacts by the oil and gas industry. This analysis highlights the need for the public FracFocus database to add more data fields.

Table 5.1: **Comparison of Eagle Ford Shale and Spraberry/Wolfcamp, Jan. 2011 - Apr.2013**		
	South Texas: Eagle Ford Shale Area	***West Texas: Spraberry/Wolfcamp Area***
Avg. Water Use per Well	~5,00,000 gallons	~910,000 gallons
No. of Wells Analyzed	> 5,000 wells	> 7,400 wells
No. of Counties for Area	27 counties	11 counties
Proppant Loading in Region, 2012*	1 pound/gallon*	0.9 pounds/gallon*
Brackish Water Use (%)	Variable by Operator	Variable by Operator
Recycled Water Use (%)*	<1%*	2%*

** Nicot, et. al, 2012*

There are two prominent trends the south and west Texas regions have displayed through the qualitative analysis. First, and foremost, operators within the two areas are utilizing brackish water and recycling/reuse techniques relatively more frequently compared to a decade ago. Operators are becoming more aware other stakeholder's input on the issue of large amounts of water a HF event uses, and more corporate "social responsibility" is being placed in fostering sustainability within companies. Brackish water use will increase in the coming years in Texas, especially in west Texas due to the increasing water needs and vast infrastructure development that has already occurred within the region, as well as the quicker returns on large amounts of flowback water from a well (Nicot, et al., 2012). The Eagle Ford region will continue to experience growth in upstream development for the oil and gas industry. Recycling and reuse in the region will be less prominent than brackish water use due to the relatively slow return of flowback water and the lack of infrastructure for recycling and reuse (Nicot, et al., 2012; Strause, 2013).

5.3 County Results

This study also evaluated three counties within the Eagle Ford region, looking at average water use trends from January 2011 to the end of May 2013 for Dewitt, Dimmit, and Gonzales counties. *Figure 5.3* shows the average water use in DeWitt county was approximately 3.4 million gallons of water per a well, and Gonzales county had a similar average use of 3.8 million gallons of water per well. Dimmit, on the other hand had closer to 5.6 million gallons of water used per a well on average as seen by *Figure 5.3*. Dimmit County showed significant increases in the average water use per a well from 2011 to 2013, rising to over a million gallons of water use per a well on average. Gonzales and DeWitt counties did not have an identifiable trend over time for average water use per well. The results for the Eagle Ford region and the three counties within the region show that there is some variability on average water use across the region.

This study also evaluated three counties within the Spraberry/Wolfcamp region, looking at average water use trends from January 2011 through April 2013 for Glasscock, Midland, and Upton counties. *Figure 5.3* shows that the average water use in Glasscock county was approximately 1.1 million gallons of water per a well, and Upton county had a similar average use of about 1.1 million gallons of water per well. Midland County had an average water use per well of about 880,000 gallons, making this county the lowest average of the six counties being analyzed. Upton County showed the largest increase in growth of water use in the Spraberry/Wolfcamp region between 2011 and 2012. All three counties within this region had a slight decrease in water use between 2012 and 2013, making 2012 the year that all three counties has the largest water use on average.

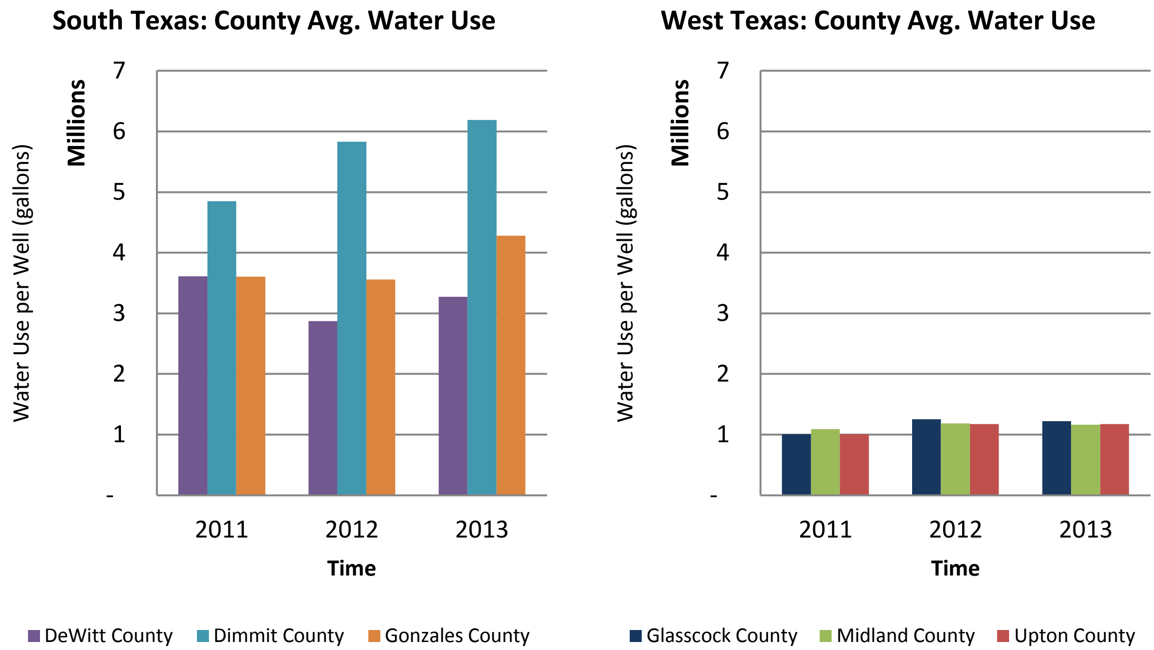


Figure 5.2 – These graphs show the average water use over time for each of the six counties analyzed in this study.

Between 2011 and 2013, there were an increasing amount of oil wells relative to gas wells during upstream development due to several market factors pushing operators to develop more oil resources rather than gas resources. The price for oil was and is significantly higher than the price of natural gas (Bloomberg, 2013). This is important because the counties with more water use in this analysis, Dimmit and Glasscock have had the most activity in recent past within them due to their location over oil resources which being heavily developed. The TWDB data displayed in *Table 1.1* also shows that the mining category can be a larger percentage of local use than the states 1% mining water use. In Dimmit county, mining represented over 30% of that county' overall water use, and it also has the highest water volume average used per well. Dimmit County's total water use has decreased from 2010 to 2011, but the mining category expanded to be a larger component of water use in the county. Water volume use from the oil and gas industry can have localized impacts that must be assessed frequently in areas with high water stress.

5.4 Regulations Overview

Groundwater managers have future challenges to overcome that the oil and gas industry will have an increasingly large hand in, including brackish groundwater development, increasing needs for energy development operations, and the increasing legal dynamics and uncertainties surrounding groundwater in Texas (Steinbach, 2013a). When it comes to water use in Texas, GCDs have a large role in what the groundwater users can and cannot use. GCDs have the authority to make the oil and gas industry get permits for water supply, as well as putting restrictions on those permits that makes an operator submit information about the use of the well (Steinbach, 2013b). GCD rules are not consistent from one district to another, and this creates less efficiency in the regulatory environment that the oil and gas companies are operating under.

Most GCDs have relatively small funding and the lack of time and resources to effectively manage the groundwater within the district. Also, each GCD has elected officials to staff a district's needs. The TWDB cannot assist all of the GCDs within the state, and therefore, the joint planning process becomes essential for accuracy on local and regional levels in water use estimations. This can be rather difficult and as this analysis has concluded, there are several different estimates for the oil and gas industry's water use in the Eagle Ford and Permian Basin regions. The transient and temporary nature of the oil and gas industry does not ease the estimation process for local water planners. GCDs also lack funding mechanisms that are sometimes not approved by voters in the district boundaries (Porter Jr., 2013). The GCDs in Texas have budgets that range from $20,000 to over $2 million annually, allowing for a vastly different operating budget between the different GCDs (Porter Jr., 2013). For example, the Gonzales County Underground Water Conservation District gathers over $125,000 in taxes annually, as well as collecting fees and interest of about $78,000, equating to a little over $200,000 in total revenue (Porter Jr., 2013). Gonzales County Underground Water Conservation District has close to $250,000 in total expenses, which is more than the revenues the district is bring in (Porter Jr., 2013). Not only does the budget not match up, but this district also has a lack of an accurate count on the exempt wells within its boundaries (Porter Jr., 2013). Exempt wells are water wells that are not required by law and by the GCD to obtain a permit to drill a well. Most of the oil and gas water wells are exempt, although, some GCDs may be required to declare the well and potentially record withdrawals. Funding mechanisms and better estimations of exempt wells and what the oil and gas industry is utilizing within a district is necessary for better water planning across the state and in future plans.

The RRC's role in collaborating with the oil and gas industry within Texas is vital for the continued improvement of regulations and development of the oil and gas resources. The promotion of recycling and reuse projects will continue to be an important point for the RRC to initiate with operators, especially in areas where water supplies will not meet water demands. The industry's role is also important due to their increased collaboration with different entities, like the RRC, to accurately portray their views on particular issues. The oil and gas industry could also benefit by considering the water needs of their operations on a regional level (Rahm and Riha, 2012). Many operators already have this mentality and consider more than just cost when looking at water management solutions for HF. The motivation to explore recycling/reuse techniques as well as waterless fracking technologies is important and will become more vital in the near future for regions that are drought stricken.

5.5 Changing Water Needs

There are changing water needs for the state in the next fifty years, which must be accounted for in the regional planning. Oil and gas water use, although relatively small on a state wide basis, accounts for large percentages of water use for some counties, and must be accurately assessed in the regions with the heaviest activities, like the Eagle Ford and the Spraberry/Wolfcamp formations. The consistently changing nature of the oil and gas industry is not something water planners are adept at assessing for long periods of time, which the state water plan calls for, and therefore an assessment of different scenarios of water use by the oil and gas industry for region would be beneficial to portray a more accurate idea of the upstream development needs, as done in Nicot, et al. (2012). The actual water used compared to the past projections showed a high amount of inaccuracy in the projects, and being able to track the oil and gas water use in a GCD is hardly possible in some areas (Nicot, et al., 2012). Accurately assessing the changing water needs for the oil and gas industry in both the south Texas and the west Texas region will be important as other larger water users like irrigation will have increasing amounts of unmet needs. Conservation strategies also play a role in the water plans, and assessments for different conservation strategies the oil and gas operators can utilize during upstream development will also be beneficial.

Chapter 7: Conclusion

7.1 Conclusion

In conclusion, the FracFocus database that Texas oil and gas operators are obligated to submit well data to lacks particular data inputs that allow for a complete evaluation of regional water use impacts. FracFocus is a publically accessible database for several different stakeholders to utilize to explore water use impacts by the oil and gas industry. The oil and gas industry can have localized water use impacts, especially on a county level in Texas. Although there was a lack of a robust data set open to public access and use for this study, the data did provide some insight into the current status of the two regions. Also, this study inferred that are several gaps in collaboration between entity representatives from various stakeholders, especially between oil and gas operators and regional water planners. Collaboration is lacking due to competition, different regulator roles, rapid growth, a lack of structure to promote efficient and continuous collaboration, and a lack of in-depth transparency.

This analysis shows that industry in these two regions are slowly progressing towards the use of brackish water due to some political factors and operators' desires to have a "social license to operate", but not due to significant economic, financial, or regulatory influences. The industry will continue to utilize groundwater as the major source of water in both regions, just as all the other water users in these areas do. Both regions are expected to have unmet water needs and conservation strategies by other water users will prove to be a vital component of future water plans (TWDB, 2012). The industry has had no large scale recycling/reuse options in the areas beyond some pilot programs, except these techniques are expected to increase in the west Texas region in the near future.

A continued promotion of transparency for the industry's practices in areas like west and south Texas, where drought is occurring, is an important element for regulators. Due to the controversy surrounding this topic, this study faced several different obstacles that created a dynamic of cautious experts and professionals. The data set publically available to utilize for analysis was also a restrictive element and lacked ease of flexible access, consistency, and accuracy. Furthermore, access to a more robust and holistic data set for a regional water use by the oil and gas industry is imperative to gather more accurate estimations of water use by the oil and gas industry, as well as to better the understanding of water planners for future oil and gas developments.

Further research beyond this study could include conducting a similar study with more data from FracFocus from June 2013 on, which accommodates all of the changes that have occurred within the regulatory environment and database structure. This data will contain fewer errors and as well as all the operators in the Texas region. Room exists to assess the dynamic relationship between operators, service providers, and water use, to see potential effects from the amount of water use from particular service providers, contractual obligations, and implemented water management plans. A further in-depth understanding of joint planning structures and if the bottom-up approach in Texas water planning is accurately portraying the correct estimations of water in the future. Finally a potential study on brackish water dynamics and appropriately defining brackish water beyond just TDS concentrations would be useful in the regulatory environment.

This study to investigate if water stressed areas are impacted on a local scale by oil and gas operations brings to light the lack of easily accessible and flexible data to weigh the various components for the Eagle Ford and Spraberry/Wolfcamp regions. Although there are significant improvements in data available, the lack of holistic data to conclusively analyze the oil and gas industry’s water use in a local area should be reassessed. Shale play development will continue to be a topic that has many stakeholders involved and the inter-communication of those stakeholders, like oil and gas operators and water planners, is vital for the continued planning and improvement of impact assessments.

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